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New Directions of STEM Research and Learning in the World Ranking Movement

A Comparative Perspective

Edited by
John N. Hawkins, Aki Yamada, Reiko Yamada, and W. James Jacob

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International and Development Education
ISBN 978-3-319-98665-4 ISBN 978-3-319-98666-1 (eBook)
https://doi.org/10.1007/978-3-319-98666-1

Library of Congress Control Number: 2018952637

This Palgrave Macmillan imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface: The Impact of STEM Research in a Knowledge-Based Society and the Need of Integrated Study of STEM and Other Disciplines

The impact on the knowledge economy in a globalized world has become larger and larger in recent years and there is a growing expectation and demand for innovation in higher education. It is generally expected that Sciences, Technology, Engineering, and Mathematics fields of study will take a leadership position in innovation. The word STEM coins the widely recognized concept of integration between science, technology, engineering, and mathematics. Many countries, such as the United States, United Kingdom, Australia, Singapore, China, Japan, and others put more emphasis on Science and Technology policies than other fields of study. Eventually, STEM education reform from K-12 to higher education has become increasingly important. Many countries devise policies to increase the number of university students as well as graduate students in STEM fields and to connect university research with industry to create a foundation for future job markets. At the K-12 level, the issue of upgrading the quality of STEM teachers is also being discussed.

Research in STEM fields has many commonalties in content, innovative aspects, and direction. Therefore, researchers worldwide submit their papers to distinguished international journals published in English. Acceptance, as well as citation rate, becomes an important indicator in the world ranking of universities. Thus, government STEM-oriented policies are closely related to the world ranking competition. Many universities in the world are therefore forced to become conscious of world ranking regimes, to secure more research funding, more foreign students, increase their world reputation, and to get national funding. Thus, STEM disciplines have received a disproportionate amount of attention largely due to the link with global ranking systems.

On the other hand, in 2015, the issue of restructuring the social sciences and humanities (SS/HUM) in the context of the STEM emphasis at the university level became a national issue in Japan. Nobody contests STEM fields' important role in research and development, with respect to future jobs and the improvement of global ranking scores. The abundance of STEM-oriented policies obscures the importance of other disciplines such as humanities and social sciences. At the same time, there has been a call for interdisciplinary collaboration based on STEM and other disciplines. There is a growing concern that students in STEM disciplines need to acquire specialized knowledge based on other disciplines to acquire global competences, such as communication skills, intercultural knowledge and skills, and interdisciplinary contextualization and innovation. This raises the question about the future direction of STEM education in higher education. Is it important to integrate STEM fields with other fields, such as humanities, arts, and social sciences? Should STEM students be exposed to international education and exchange programs as other students do in the humanities and social sciences.

This project intends to analyze the dominance of STEM fields in various university rankings and the reason why and how many governments in the world disproportionately give value to STEM fields. STEM is an up and coming hot theme. However, most of this attention focuses on research which leads to national productivity, innovation, and world competitiveness. There is little research to discuss the relationship of recent world science and technology policies, STEM disciplines and the world university ranking movement. The world university ranking movement is also a new trend and it influences higher education policy globally. Thus, research on STEM receives large amounts of research funding, influences the mobility of foreign students, and develops industry and university collaboration.

Second, although there is a general agreement that STEM fields are important, we also examine the role of interdisciplinary and multidisciplinary approaches for a revised STEM education. What should be the direction of STEM higher education in the future? Both purposes are analyzed comparatively in examples from the United States, Canada, Japan, China, Korea, and Taiwan. The study is a comparative analysis that will clarify the commonalities and differences between countries. There is a hypothesis that many countries covered in this study have commonalities of science- and technology-oriented policy in the knowledge-economy society, however, there are some differences of approach for STEM higher education and STEM higher education reform. We will examine what makes commonalities and differences between countries and how we might propose new directions for STEM higher education in the twenty-first century. The chapters of this book illustrate some new directions of STEM higher education from the perspective of twenty-first century types of learning outcomes and thus focuses on the need of developing an interdisciplinary approach for STEM higher education reform.

The Introductory Remarks written by John N. Hawkins illustrates the existence of a dilemma of STEM integration in the Arts, Humanities, and Social Sciences and argues that this dilemma has had profound implications for the current debate on the value and action implications of various ranking regimes.

In Chapter 1, Reiko Yamada analyzes how globalization and knowledge-based economy have impacted the promotion of STEM human resource-oriented policies worldwide in comparative perspective and then, examine the necessity of global competences for STEM college students from the interdisciplinary aspect.

In Chapter 2, William R. Stevenson III shows the relationship of university ranking and field of STEM, examined from the historical perspective. It becomes clear that for over a century, universities have been assessed and ranked according to both outcome-based approaches and student-oriented input-based criteria.

It is recognized that science and innovation will increase the productivity and bring the well-paid jobs and enhance competitiveness and result in the economic growth. Chief Scientist (2014) states that the advancement of science technology and growing occupations require technology and skills in STEM fields. Also, STEM research is recognized to contribute to increasing world university rankings. However, emphasis on STEM fields may increase inequality issues in higher education. In Chapter 3, Tristan Ivory examines inequality issues arising from emphasis on STEM fields at three general levels—the individual, institutional, and national.

Chapter 4 written by Jason Cheng-Cheng Yang demonstrates how the impact of ranking also can be found on faculty behaviors at top universities in Asia and university's internal allocation of funds on different subjects. He chose Taiwan as a case to study the relationship between world higher education ranking and STEM research.

Chapter 5 by Grant Jun Otsuki discusses cases in which people have worked at and across this boundary in ways that defy easy categorization as "STEM" or "H&SS." These interactions, it is suggested, are as important to the work of scientists as they are under-recognized. This will lead us to a discussion at the end of some of the consequences of the persistence of this boundary despite its porousness.

In Chapter 6, Aki Yamada shows the direction of interdisciplinary collaboration in US higher education and then analyzes similar developments in Japanese higher education, such as the Empowerment Informatics Ph.D. Program (EMP Program) at the University of Tsukuba. These institutions merge STEM majors with of artists, humanists, and social scientists in collaborative classwork, research and development, and field work.

Although there are limitations to the measurement of global poverty, it is a large enough indicator to draw the interest of global and regional development banks, bilateral and unilateral aid from governments, and research initiatives from companies, think tanks, and universities. Concerning global poverty research, there are eight development labs (at seven universities) funded by USAID. In Chapter 7, Christopher S. Collins focuses on the role of interdisciplinary work at university development labs.

In Chapter 8, Byung Shik Rhee aims to fill that gap by examining the humanities competencies of STEM students enrolled in two Korean research universities, one comprehensive university and one science and technology university by asking the following questions: (1) What are the current humanities-competency levels of STEM undergraduate students at two research universities in Korea? (2) Do the humanities competencies of STEM students change by year during college?, and (3) How are the humanities competencies of STEM students related to faculty mentoring, student engagement, institutional climate, and liberal arts courses taken?

From the 1950s, strengthening science and technology became the core policy of Chinese education and thus, China is now matching and surpassing most of the western countries. But this overemphasis on science has led to a neglect of studying the arts and there exists a tendency to generally undervalue the arts and regard them as unimportant. Chapter 9 by Yi Yang analyzes Chinese arts education policies in a new era in relation to the perspective of "From STEM to STEAM."

In Chapter 10, Masaaki Ogasawara demonstrates that consistent Japanese special higher education policy on STEM field after Meiji Era had contributed to produce many graduates with technical and scientific abilities to lead our industrial society. However, at present, Japanese STEM disciplines are suffering from the decline in the number of students who have interests in STEM fields. He argues that the existing traditions and customs in the Japanese system has caused the present STEM issue.

Chapters in this book illustrate some new directions of STEM higher education from the perspective of twenty-first century types of learning outcomes and thus focuses on the need of developing an interdisciplinary approach for STEM higher education reform.

Kyoto, Japan Reiko Yamada

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Notes on Contributors

Christopher S. Collins is an Associate Professor of Higher Education at Azusa Pacific University and serves as an Associate Director for the Asia Pacific Higher Education Research Partnership (APHERP). He is interested in research on the role of higher education related to poverty reduction, knowledge extension, public good, and social rates of return. Past publications include *Higher Education and Global Poverty: University Partnerships and the World Bank in Developing Countries* (Cambria Press, 2011) and *Education Strategy in the Developing World: Revising the World Bank's Education Policy* (Emerald Group Publishing Limited, 2012). In addition, he has published articles in *The Review of Higher Education*, *Higher Education*, and the *Journal of Higher Education*. He earned a Ph.D. in education from the University of California, Los Angeles.

John N. Hawkins is a Professor Emeritus at the University of California, Los Angeles and former Co-Director of APHERP, East-West Center. Hawkins is a specialist on higher education reform in the United States and Asia and the author of several books and research articles on education and development in Asia. Recent books include *Changing Education: Leadership, Innovation, and Development in a Globalizing Asia Pacific* (with Peter D. Hershock and Mark Mason, Springer, 2007) and *Policy Debates in Comparative, International, and Development Education* (with W. James Jacob, Palgrave Macmillan, 2011). He has served as President of the Comparative International Education Society and Editor of the *Comparative Education Review*.

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W. James Jacob is a Professor of Higher Education Leadership in the Department of Leadership at the University of Memphis. He also serves as Co-Director of the Center for the Study of Higher Education and as a member of the Leadership Memphis Executive Program. Prior to joining the University of Memphis, he served for 10 years at the University of Pittsburgh as Director of the Institute for International Studies in Education. He is the Co-Editor of two book series related to the development of comparative, international, and development education scholarship: *International and Development Education* (Palgrave Macmillan) and *Pittsburgh Studies in Comparative and International Education* (Sense Publishers). His most recent books include *Strategic Transformation of Higher Education: Challenges and Solutions in a Global Economy* (with Stewart E. Sutin, Rowman & Littlefield, 2016); *Trends in Chinese Education* (with Hongjie Chen, Routledge, 2016); *Indigenous Education: Language, Culture, and Identity* (with Sheng Yao Cheng and Maureen Porter, Springer, 2015); *Community Engagement in Higher Education: Policy Reforms and Practice* (with Stewart E. Sutin, John C. Weidman, and John L. Yeager, Sense Publishers, 2015); and *Policy Debates in Comparative, International, and Development Education* (with John N. Hawkins, Palgrave Macmillan, 2011). He has written extensively on comparative, international, and development education topics with an emphasis on higher education.

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Grant Jun Otsuki (http://www.gjotsuki.net/) is a Lecturer in the School of Social and Cultural Studies at Victoria University of Wellington, New Zealand. From 2015 to 2017, he was an Assistant Professor of Anthropology at the University of Tsukuba, Japan. His research focuses on the anthropology of history of science and technology, the anthropology of contemporary Japan, and science and technology studies. His field research has investigated the practices of wearable technology and robotics researchers in Japan, the transhumanist movement in North America, and the use of technology in Japanese popular culture.

Byung Shik Rhee is a Professor of Higher Education and Director of Center for Global Higher Education at Yonsei University. He previously served as a visiting scholar within the Higher Education Research Institute at the University of California, Los Angeles. He has served as an Associate Dean of the University College at Yonsei University, as an advisory member of the Presidential Committee on Education Innovation, as well as in the President's Office of Education, Science and Technology, and Culture. He holds a Ph.D. in Higher Education (Organizational Behavior and Management) from the University of Michigan. His current research interests are impact of college on students, institutional performance, and management and leadership in higher education institutions.

William R. Stevenson III is an Associate Professor and the current Chair of the Department of Education and Culture at Doshisha University. He received a Ph.D. in Japanese History from the University of Hawaii at Mānoa. He teaches and publishes primarily in the field of education history, and spends his free time exploring the hills surrounding Kyoto with his wife and three young boys.

Aki Yamada received her Master of Arts in American Studies from Doshisha University, Kyoto, Japan, studying at Stanford University for one year as a Freeman Spogli Institute Visiting Researcher. In 2015 she completed her Ph.D. in Education at UCLA, writing her dissertation on new Japanese migrants and immigrants living in the United States. Her research interests include globalization, contemporary Asian immigration, transnational identity, and internationalization of higher education. Aki is now working as an Assistant Professor in the Empowerment Informatics program at University of Tsukuba. Her recent work includes "Changing Dynamics of Asia Pacific Higher Education Globalization, Higher Education Massification, and the Direction of STEM Fields for East Asian Education and Individuals" in *Redefining Asia Pacific Higher Education in Contexts of Globalization Private Markets and the Public Good* (Palgrave Macmillan, 2015).

Reiko Yamada is Dean and Professor of the Faculty of Social Studies and Director of the Center for Higher Education and Student Research at Doshisha University, Kyoto, Japan. She was the inaugural President of the Japanese Association of the First-year Experience. She received a Ph.D. from UCLA. She is the author of *For the Quality Assurance of Undergraduate Education* (Toshindo, 2012), and editor of *Quality of Higher Education and Its Evaluation: Japan and the World,* (Toshindo, 2016). Her recent publications include *Measuring Quality of Undergraduate Education in Japan* (Springer, 2014), "Comparison of Student Experiences in the Era of Massification: Analysis of Student Data from Japan, Korea and the USA" in *Managing International Connectivity, Diversity of Learning and Changing Labour Markets: East Asian Perspectives* (Springer, 2016).

Jason Cheng-Cheng Yang is an Associate Professor in the Graduate Institute of Educational Administration and Policy Development at National Chiayi University (NCYU), Taiwan. He completed his Ph.D. degree in International Comparative Education at University of California, Los Angeles in 2010. His research interests include higher education administration, higher education policy, and comparative education. His research articles cover topics ranging from management in university to higher education policy issues in Taiwan and other Asian countries. His current research projects focus on exploring organizational justice in higher education and the hybridizing process of Western forces and local academic culture in the Taiwanese higher education system.

Yi Yang received her M.A. and Ph.D. in Education from Kyoto University. Her research areas include educational thought, history of education, aesthetic education, arts education, and comparative education. She is an Associate Professor of the College of Contemporary Education at Chubu University. Her recent publications include an article in *Social Science Review* titled "A Study on the Development of the Aesthetic Education Movement A: Cai Yuan-pei's Practice from the 1910s to the 1920s."

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Series Editors' Introduction

We are pleased to introduce another volume in the Palgrave Macmillan International and Development Education book series. In conceptualizing this series we took into account the extraordinary increase in the scope and depth of research on education in a global and international context. The range of topics and issues being addressed by scholars worldwide is enormous and clearly reflects the growing expansion and quality of research being conducted on comparative, international, and development education (CIDE) topics. Our goal is to cast a wide net for the most innovative and novel manuscripts, both single-authored and edited volumes, without constraints as to the level of education, geographical region, or methodology (whether disciplinary or interdisciplinary). In the process, we have also developed two subseries as part of the main series: one is co-sponsored by the East-West Center in Honolulu, Hawaii, drawing from their distinguished programs, the International Forum on Education 2020 (IFE 2020) and the Asia Pacific Higher Education Research Partnership (APHERP); and the other is a publication partnership with the Higher Education Special Interest Group of the Comparative and International Education Society that highlights trends and themes on international higher education.

The issues that will be highlighted in this series are those focused on capacity, access, and equity, three interrelated topics that are central to educational transformation as it appears today around the world. There are many paradoxes and asymmetries surrounding these issues, which include problems of both excess capacity and deficits, wide access to facilities as well as severe restrictions, and all the complexities that are included in the equity debate. Closely related to this critical triumvirate is the overarching concern with quality assurance, accountability, and assessment. As educational systems have expanded, so have the needs and demands for quality assessment, with implications for accreditation and accountability. Intergroup relations, multiculturalism, and gender issues comprise another cluster of concerns facing most educational systems in differential ways when one looks at the change in educational systems in an international context. Diversified notions of the structure of knowledge and curriculum development occupy another important niche in educational change at both the precollegiate and collegiate levels. Finally, how systems are managed and governed are key policy issues for educational policymakers worldwide. These and other key elements of the education and social change environment have guided this series and have been reflected in the books that have already appeared and those that will appear in the future. We welcome proposals on these and other topics from as wide a range of scholars and practitioners as possible. We believe that the world of educational change is dynamic, and our goal is to reflect the very best work being done in these and other areas. This volume meets the standards and goals of this series and we are proud to add it to our list of publications.

Los Angeles — John N. Hawkins
University of California

Memphis — W. James Jacob
University of Memphis

Introduction: The Dilemma of STEM—Social Science/Humanities Re-Integration

Although academic interest in this topic has been steadily rising, serious discussion of the STEM—Social Science and Humanities (hereafter SS/HUM) divide has been present for at least 20 years. My own interest in this topic dates back to a project I co-funded at UCLA by Professor Etel Solingen of the University of California, Irvine entitled *Scientists and the State*, later published by the University of Michigan Press (Solingen 1994). Here the focus was on state/scientist relations, and the influence of domestic and international political economies on this relationship. Prior to this project, little work had been done that looked at the interactions and integration of science and the social sciences. This book did not delve into the humanities as such, but the complexity of science—non-science relations captured my attention. This was prior to the current fascination with STEM and non-STEM relations, but clearly carved out some of this territory as part of the ecology of the STEM/humanities/social science problematic and what I call here the dilemma of this complexity: the dilemma of STEM integration in the arts, humanities, and social sciences. It is a dilemma because it is unclear whether the driving force for re-integration proceeds from STEM to SS/HUM or from SS/HUM to STEM—or both? And this dilemma has had profound implications for the current debate on the value and action implications of various ranking regimes.

The dilemma is also relevant for assessing differential values regarding STEM in Asia and the West. Studies of international students from Asia in the United States in the social science and humanities fields and those in the STEM fields reveals a number of communication barriers that are significant regarding the choice of field of study (Yamada 2015). Finally, the forces and factors that are encountered in the structure of knowledge within higher education drive this debate in some important respects. The curriculum in higher education has proven to be an essential yet relatively unchanging part of the dominant educational paradigm. We are familiar with a disciplinary narrowness, a silo-like separation of knowledge that has changed little despite the rise of interdisciplinary studies in recent years (Hawkins 2007; Jacob 2015). It is sometimes forgotten that the term "science" was invented in the nineteenth century when it emerged from the fields of philosophy and humanities. Thus, we are really talking about the re-integration of STEM and non-STEM fields (Gutting 2013).

The Great Debate

As is so often the case, these kinds of debates become binary, that is, there are scholars on both sides of the issue that argue persuasively for their intellectual cause and point of view. In this case, once it has become agreed upon that it would be desirable for the STEM fields and those of the social sciences and humanities to find a way to work together, indeed to enrich each other, arguments emerged as to why this is such difficult work. Those in the SS/HUM community have passionately argued that the STEM fields are in dire need of the enrichment that the disciplines that makeup SS/HUM can offer. Those in the STEM fields have of course argued just the opposite. And those scholars outside of academia (in such US organizations, as, for example, the National Foundations for the Humanities and the Arts, and the National Foundation for the Sciences) have provided funding for studies on novel ways in which the two camps can "integrate" to the benefit of both.

It is worthwhile to examine for a moment the arguments posed by both sides by two of their most articulate spokespersons: Gary Gutting of the University of Notre Dame and Steven Pinker of Harvard University. Gutting (2013) makes a strong case that the way forward is for the SS/HUM fields to take the lead inasmuch as the STEM fields are basically lacking in even a cursory knowledge of philosophy or the humanities. He points out that "philosophy of mind" scholars are well versed in the field of neuroscience and cognitive science, but cognitive scientists are not well prepared in philosophy or humanities. This gap in SS/HUM among STEM scholars is not limited to this one area but can be seen across the disciplines (e.g., historians of science, philosophy of physics, political economy, and so on). More specifically, Gutting (2013, p. 2) notes:

> Historians of science are also immersed in the areas of science they study. Graduate programs in the discipline typically expect strong undergraduate majors or even a master's degree in a particular science.... Thomas Kuhn, the most influential historian of science ever, had a doctorate in physics from Harvard. By contrast, few current scientists do serious work in the histories of their disciplines.... There is, then good reason to think that the greater problem is scientists' failure to attend to what is going on in the humanities.

What would STEM scholars have to gain by learning more about the SS/HUM fields? There are at least several positive contributions that might be cited according to SS/HUM scholars:

- Broader thinking and reasoning skills;
- Historical and cultural perspectives on fields of study within STEM;
- Critical thinking skills improvement;
- Global collaboration enrichment;
- Improved communication skills;
- A greater focus on meaning and ethics;
- The addition of social context to STEM; and
- The possibility that STEM could change to STEAM (Science, Technology, Engineering, *Arts*, and Mathematics).

Pinker (2013), however, offers another point of view in an article provocatively entitled "Science is Not Your Enemy." He argues that STEM scholars often do reach out to those in the SS/HUM fields but find that these efforts are deeply resented and often rebuffed. This rejection of STEM by SS/HUM comes from both the political right and left. From the right, science is viewed as an attack on religious values, culture, and belief systems in general and presents itself as "soul-less" to those in SS/HUM fields. From the left, it is pointed out that STEM is responsible for a variety of social ills and historical disasters including scientific racism, imperialism, eugenics, two world wars, and horrific and destructive weapons among others.

Pinker counters these arguments by noting that STEM scholars and fields of study have much to offer those in the SS/HUM fields as well as society in general. In short:

- To understand that the world is intelligible;
- That acquisition of knowledge is "hard," follows the scientific method, gets us beyond magic, superstition, and myth;
- That STEM contributes to the fulfillment of moral and humanistic values by promoting empirical evidence for human development and growth; and
- That the application of "data science" offers much potential for an expansion of humanities (e.g., digital humanities—origin and spread of ideas, networks of intellectual and artistic influence, persistence of historical memory, etc. (Pinker 2013, p. 5)

In summary, Pinker concludes: "Surely our conception of politics, culture, and morality have much to learn from our best understanding of the physical universe and our makeup as a species" (p. 9).

Thus, both the Gutting and Pinker arguments (though presented just briefly here) make a lot of sense from their own point of view and provide a basis for pursuing some form of integration and convergence of STEM and SS/HUM. Based on the US experience and revealed in the comments by Pinker and Gutting, it appears that a key element to such collaboration is the link between these fields of study and the labor market. In the United States, all relevant major pedagogical associations—the National Endowment for the Humanities (NEH), National Endowment for the Arts (NEA), and the National Science Foundation (NSF)—agree that each disciplinary cluster (STEM and SS/HUM) has something to offer the other. First and foremost, each of these agencies notes that improved integration results in improved career outcomes for both undergraduates and graduate students in both fields of study. This is particularly important in settings where employment opportunities are tight.

Second, NEH Chair William Adams has commented, "A holistic education provides students with a wide range of skills that better prepare them to enter the professional world." And NEA Chair Jane Chu notes "The arts uncover possibilities that can help us solve complex problems in many different fields, from science and transportation, to health care and education" (National Endowment for the Arts 2016).

A similar argument is made from the perspective of the STEM fields. The Board on Higher Education and Workforce (BHEW—National Academies of Science, Engineering and Medicine), for instance, convened more than 100 STEM scientists at their December 2015 meeting in Washington, DC; here, evidence was presented (in agreement with NEH and NEA) that integrative efforts between STEM and SS/HUM fields will lead to improved career outcomes for both STEM and SS/HUM graduates. The argument here is that STEM study helps SS/HUM students to become more critical thinkers, more innovative, and more entrepreneurial, among other gains. It was also noted that SS/HUM pedagogical approaches help STEM fields better integrate history, literature, philosophy, culture, and religion into their curriculum.

Thus, while in the United States it appears there are genuine efforts within both the STEM and SS/HUM fields to bring about a re-integration of these disciplines, at least one group of scholars has suggested that on some levels convergence of STEM and SS/HUM is already taking place. A recent study by Dunleavy, Bastow, and Tinkler (2014) argues that there has been considerable movement of STEM and SS/HUM toward each other in recent years. Their point is that if SS/HUM is viewed as a group in the way STEM is you can readily see this convergence. It occurs in several key areas.

- Methodological: utilization of systematic review of literature and data sources (this influence is largely imported from health sciences);
- Randomized and controlled trials (this has become the 'gold standard' for social sciences and in some areas the humanities);
- Use of "Big Data" displacing previous SS/HUM small data methods, such as survey data;
- Use of Digital Data—even in the humanities there are several examples of the use of digital data, including large-scale university-based programs such as UCLA's "digitizing the humanities" initiative; and
- Modes of SS/HUM and STEM communications are generally "shorter, better, faster, and free" in the world of digital scholarship (Dunleavy et al. 2014).

Some Concluding Remarks

There is no absolute conclusion to these introductory comments, inasmuch as the re-integration of STEM and SS/HUM is clearly a work in progress. Classic studies like Abbot's *Chaos of the Disciplines* remain relevant, arguing that the structure of knowledge is fluid and exists in the complex historical context of the classical disciplines, as well as the more recent rise of interdisciplinarity, the interactional field of academic disciplines, and the internal dynamics of the disciplines themselves (Jacob 2015). What we can see is that SS/HUM and STEM are not such settled terrains as we might think, but rather a complex process of group ecology, "an unrelenting process of interaction between groups" (Abbott 1999, p. 136). Or, in the prescient words of James Leach, former President of the National Endowment for the Humanities, the STEM SS/HUM tension represents a situation where

> a misconceived psychological cleavage is fast developing between the humanities and the STEM disciplines. My thesis is that the humanities and fields of inquiry related to science, technology, engineering and math are complementary rather than competitive. Each set of disciplines is essential …. Indeed, the humanities without STEM defines economic stagnation, and STEM without humanities could precipitate social disaster. (Leach 2013)

Those who promote and value the various ranking regimes would do well to take the re-integration of STEM and SS/HUM into account when factoring in their algorithms and metrics in efforts to assign values to the structure of knowledge in the modern university (Madsbjerg 2017).

In this book, we will explore several key elements of this dilemma, including the context and implications of various ranking regimes on STEM and SS/HUM interactions, particularly with respect to learning outcomes. Another focus of the book has to do with STEM and SS/HUM within the context of the arts, global competencies, and global poverty. Finally, there are chapters that illustrate this dilemma for specific settings in Taiwan and Japan. The overall goal in the book is to raise a number of research issues around the STEM—SS/HUM debate for future attention.

Honolulu, Hawaii

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References

Abbot, Andrew. 1999. *Chaos of the Disciplines*. Chicago: University of Chicago Press.

Dunleavy, Patrick, Simon Bastow, and Jane Tinkler. 2014. *How Social Sciences Are Converging with STEM*. LSE Impact Blog, 20 January 2014. London: London School of Economics. Available online at: http://blogs.lse.ac.uk/impactofsocialsciences/2014/01/20/social-sciences-converging-with-stem-disciplines/. Accessed on April 4, 2018.

Gutting, Gary. 2013. "Science's Humanities Gap." *The New York Times*, September 18.

Hawkins, John N. 2007. "The Intractable Dominant Educational Paradigm." In *Changing Education: Leadership, Innovation and Development in a Globalizing Asia Pacific*, edited by Peter D. Hershock, Mark Mason, and John N. Hawkins, 137–162. Dordrecht, The Netherlands and Hong Kong: Springer and Comparative Education Research Centre, University of Hong Kong.

Jacob, W. James. 2015. "Interdisciplinary Trends in Higher Education." *Palgrave Communications* 1 (1): 1–5. https://doi.org/10.1057/palcomms.2015.1.

Leach, James A. 2013. "STEM and Humanities, a False Dichotomy." Speech given at the University of Illinois at Urbana–Champaign, Distinguished Lecture Series, Champaign, IL, April 17, 2013. Available online at: https://www.youtube.com/watch?v=AbkGSQJCXxQ. Accessed on April 4, 2018.

Madsbjerg, Christian. 2017. *Sense Making: The Power of the Humanities in the Age of the Algorithm*. New York: Hachette Books.

National Endowment for the Arts (NEA). 2016. *NEH and NEA Support New Higher Education Study on Integration of STEM with Arts and Humanities*. Washington, DC: NEA.

Pinker, Steven. 2013. Science Is Not Your Enemy. *The New Republic*, August 6.

Solingen, Etel. 1994. *Scientists and the State*. Ann Arbor, MI: University of Michigan Press.

Yamada, Aki. 2015. "Changing Dynamics of Asia Pacific Higher Education Globalization, Higher Education Massification, and the Direction of STEM Fields for East Asian Education and Individuals." In *Redefining Asia Pacific Higher Education in Contexts of Globalization: Private Markets and the Public Good*, edited by Christopher S. Collins and Deane E. Neubauer, 117–128. New York: Palgrave Macmillan.

CHAPTER 1

Educational Policy Across the World: How STEM Disciplines Deal with Twenty-First Century Learning Outcomes and Challenges

Reiko Yamada

Introduction

The impact of the knowledge-based economy in the globalized world has steadily increased in recent years leading to a growing expectation and demand for innovation through university researches. In particular, under such circumstances, it is expected that STEM will play a central role in innovation. Although the term STEM is not yet prevalent in Japanese society, the concept of integration between science, technology, engineering, and mathematics (STEM) has become increasingly well-recognized over the last few years.

In recent years, Organisation for Economic and Co-operative Development (OECD) countries have promoted science and technology polices, and a number of Asian countries, such as China, Korea, Malaysia, and India have announced policies to increase number of

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*,
International and Development Education,
https://doi.org/10.1007/978-3-319-98666-1_1

university graduates with STEM degrees (PCAST 2010, 2012; Office of the Chief Scientist 2014; House of Lords 2012). In Japan, the Ministry of Education, Culture, Sports, Science and Technology (MEXT)'s strategy of developing human resource in science and technology was announced to the public in 2015, and the 5th Science and Technology Basic Plan was announced by cabinet office in 2016. These two plans take the stance that human resources in science and technology are closely associated with innovation in society. Similar STEM-oriented policies have been adopted worldwide. It is widely recognized that science and innovation increases productivity, brings well-paying jobs, enhances competitiveness, and thus leads to economic growth. The Office of the Chief Scientist (2014), in Australia, reported that economic growth over the last 50 years in the United States and Australia is largely due to the advancement of science and technology, and that 75% of occupations in growth areas require a STEM background.

Research in STEM fields, no matter where in the world it is conducted, shares many commonalties in terms of their content, innovation, and future directions. Therefore, researchers around the world can submit papers to distinguished international journals published in English and compete with each other. Acceptance rates and citations rate serve as important indicators for deciding the global ranking of universities. Thus, it stands to reason that STEM-related government policies are closely related to universities' competitiveness in world rankings.

Engineering education, in particular, is universal, as evidenced by the establishment of educational standards including learning outcomes, curriculum, and pedagogies in the Washington Accord. As a case in point, the educational standard established by Japan Accreditation Board for Engineering Education (JABEE) conforms to the standard set by the Washington Accord. It is evident that globalization has accelerated the convergence of engineering standards. At the same time, the number of STEM college students, including engineering students who participate in study abroad and overseas internship programs, has been growing in recent years. The number of STEM degree holders who work and conduct research overseas has seen a similar rise.

In this paper, I analyze how globalization and the knowledge-based economy have impacted the promotion of STEM-related human resource policies worldwide from a comparative perspective and examine STEM college students' need for interdisciplinary global competences.

Science and Technology Policies Around the World

In this section, we examine official reports related to the science and technology policies of the United States, Australia, England and Japan, and identify common trends between these countries in term of STEM policies for higher education.

US STEM Education Policies

Specifically, in the case of the United States, we examine a series of official reports issued by (former) President Obama's advisory committee, The President's Council of Advisors on Science and Technology (PCAST).

United States Presidents have traditionally formed advisory committees of science, technology, and medical fields. In 2009, former President Obama also appointed a special advisory council, PCAST comprising distinguished scientists and engineers to augment the ability of the White House, cabinet, and other federal agencies to support economic development through the promotion of science, technology, and innovation. The advisory council issued several official reports including numerous recommendations. Whereas PCAST's purview included all science and technology policies, the reports issued in 2010 and 2012 focused on and included recommendations related to STEM education. The 2012 report titled *Engage to Excel; Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics* includes the assessment that "economic forecasts point to a need for producing, over the next decade, approximately 1 million more college graduates in STEM fields than expected under current assumptions."[1] US economic projections point out that there is a need of approximately 1 million more STEM professionals in the United States.

Kelvin K. Droegemeier delineates that "some common definitions of the STEM workforce exclude workers with less than a bachelor's degree, …Most definitions of the STEM workforce," he added, "are based on degree or occupational classifications" (National Academics of Sciences,

[1] This sentence is shown in the letter of John P. Holdren, PCAST Co-Chair and Eric Lander, PCAST Co-Chair to President Barack Obama which is contained in the report without page number.

Engineering, and Medicine 2016, p. 13). Droegemeier, however, predicts that regardless of the definitions, the size of the STEM workforce will change dramatically (National Academies of Sciences, Engineering, and Medicine 2016). He added that although only 5.4 million of the 139 million people in the US workforce in 2010 were engaged in a STEM-related job, according to the Bureau of Labor Statistics, 19.5 million individuals had obtained a bachelor's degree or higher in a STEM field, and 16.5 million individuals reported that bachelor's level STEM expertise was required at their jobs by using the data of NSF 2014 (National Academies of Sciences, Engineering, and Medicine 2016, p. 13). Droegemeier concluded that "considering the STEM workforce through all of these lenses is especially important if we wish to understand more broadly how STEM skills are used in the workplace and how these workers contribute to innovation and national competitiveness," (National Academies of Sciences, Engineering, and Medicine 2016, p. 13). This conclusion appears to criticize the effectiveness of current STEM education and STEM human resource strategy at the higher education level.

To achieve the goal of 1 million STEM degree holders, the number of university graduates with STEM degrees must increase by 34% over current rates. At the time of the report, approximately 300,000 graduates with STEM bachelor and associate degrees were produced annually. The retention rate of STEM students is less than 40%. Therefore, to achieve the target goal of 1 million additional STEM graduates, the retention rate must be increased up to 50% (PCAST 2012). As a reason for the low retention rate in STEM fields, PCAST observed that traditional introductory courses do not inspire motivation for learning and that there is a mathematics-preparation gap for incoming college students. PCAST recognized the need to improve strategies for STEM student recruitment and retention in the first two years of higher education, and provided five recommendations to transform STEM undergraduate education. The recommendations also included the transition from high school to college. The five recommendations were as follows:

1. Catalyze widespread adoption of empirically validated teaching practices,
2. Advocate and provide support for replacing standard laboratory courses with discovery-based research courses,

3. Launch a national experiment in postsecondary mathematics education to address the math preparation gap,
4. Encourage partnerships among stakeholders to diversify pathways to STEM careers and
5. Create a Presidential Council on STEM Education with leadership from the academic and business communities to provide strategic leadership for transformative and sustainable change in STEM undergraduate education (PCAST 2012, pp. II–III).

Regarding the five recommendations and concrete action plans for each recommendation, Yuichi Senda (2013) states that, for recommendation one, pedagogies with clear educational effectiveness based on teaching and learning theories should be implemented and that there is a need to show an educational effectiveness with evidence data. As examples of effective teaching methods, he points to the emerging need for active learning methods. However, as stated in the PCAST (2012) report, “a significant barrier to broad implementation of evidence-based teaching approaches is that most faculty lack experience using these methods and are unfamiliar with the vast of research indicating their impact on learning” (p. III). Therefore, implementation of these new teaching methods will require much time. It is anticipated that the federal government will provide training opportunities for faculty and support for the development of teaching materials to improve the teaching environment. Senda (2013) also points out that there is a need to develop indicators to measure the effectiveness of STEM education to the ends described above.

In 2012, former President Barack Obama decided to launch two National Science Foundation (NSF) STEM-related undergraduate education and practice projects at a cost of 100 million dollars: the *Widening Implementation and Demonstration of Evidence-based Reforms (WIDER)* and *Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics (TUES)*. These projects support STEM education reform plans promoted by community colleges as well as four-year universities. An additional 60 million dollars were included in the FY2013 budget to improve mathematics education through collaboration between the federal government and the NSF. The president’s quick adoption of action plans appears to have been aimed at cultivating human resources and increasing the competitiveness of the United States by improving STEM education.

Australian STEM Education Policies

Australia recognizes that "science and innovation are key for boosting productivity, creating more and better jobs, enhancing competitiveness and growing an economy" (Chief Scientist 2014, p. 7) because she (the Chief Scientist) understands that there is no national strategy that bears on science, technology, and innovation in Australia. Thus, the National report, *Chief Scientist, 2014* spells out the need and importance of a governmental approach to investing in STEM. In the report, four means of increasing the competitiveness of the Australian economy were presented—education and training, research, and international engagement. Here, we summarize what the report says in the sections on "Education and Training" and "Research."

The Education and Training section of the report sets out the national objective as follows: "Australian education, formal and informal will prepare a skilled and dynamic STEM workforce, and lay the foundations for lifelong STEM literacy in the community" (Chief Scientist 2014, p. 20). Underlying this objective is concern on the part of the Australian government about the continuously declining number of students at the higher education level who major in science and mathematics. Brigid Freeman (2015) points out that the wide choice and small number of required courses of university curricula at the secondary education level are the main causes of this decline. Australian students score lower on the Programme for International Student Assessment (PISA) than students from other countries. Hence, science literacy must be improved at all educational levels, from elementary, secondary, and post-secondary through to the lifelong education level in order to develop a national economy with emphasis on STEM-related industries. At the higher education level, although there is a slight increase in students majoring in medical and health science, the number of students majoring in IT fields and engineering is declining. Thus, increasing the overall number of students, as well as the proportion of female and minority students majoring in STEM fields, is recognized as an urgent objective, as is support from the government for achieving these objectives (Chief Scientist 2014; Freeman 2015).

The Research section of the report shows the Australian research strategic plans in the future and delineates several concrete recommendations. Hence, the Australian government has declared that development of research and innovation is a national goal and shows the intent to invest a proportion of its research support in areas of importance. The government expects to promote STEM-related research and development, and innovation in the future. Accordingly, providing STEM education and training, and increasing the number of STEM teachers are regarded as goals that are closely associated with the development of research (Chief Scientist 2014).

English STEM Education Policies

The report titled *Higher Education in Science, Technology, and Engineering and Mathematics (STEM) Subject*, issued by the House of Lords in 2012, presents 33 recommendations for education policies. While the policies recommended in this report have much in common with those advocated by the US and Australian government in terms of predictions related to the supply and demand of the future workforce in STEM-related fields, and the need to improve the quality of qualified STEM teachers and education, there are several positions that are unique to the English government. Regarding the transition from secondary to higher education, the report describes the existence of a mathematical skills gap. The report states that "in 2006, the Royal Society argued that the gap between the mathematical skills of students when they entered HE and the mathematical skills needed or STEM first degrees was a problem. First, lack of fluency in basic mathematical skills; and, secondly, the fact that some A level syllabuses allowed topics to be excluded which were relevant to some first degree courses" (House of Lords 2012, p. 15). The government recommended making the study of math in some form compulsory for all students post-16 and making A2 level math a requirement for students intending to study STEM subjects in higher education. In England, many foreign students tend to major in STEM fields; after graduation, many of these foreign students stay in England and find jobs in STEM fields. The report also concerns itself with the revision of immigration rules, and particularly the visa status of foreign students after they graduate. It is expected that revision of the working visa qualifications is needed to maintain the supply of workers for STEM-related jobs.

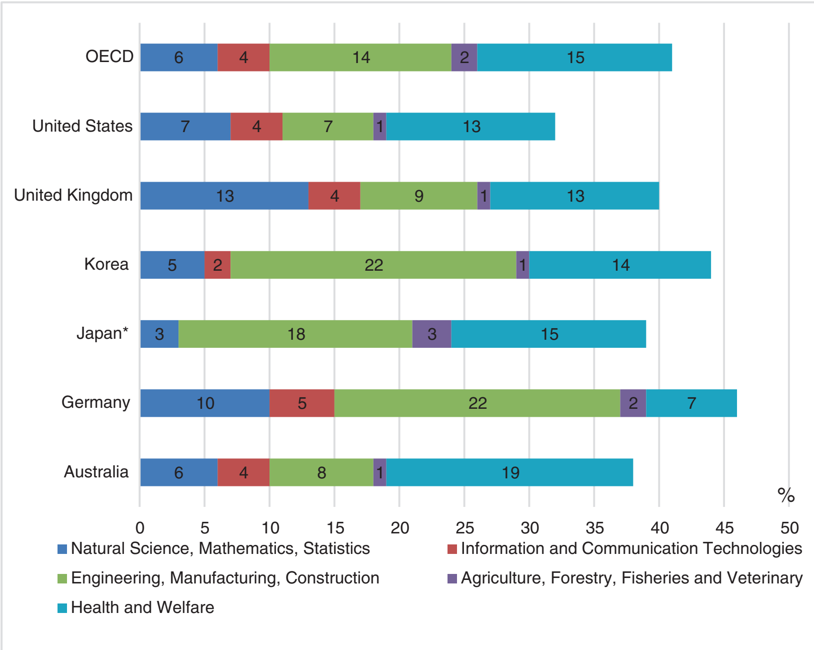
The report also presented numerous recommendations regarding quality assurance. For example, the report recommends that the Quality Assurance Agency for Higher Education (QAA)'s quality assurance of teaching and learning be updated. It also suggests that curricula and learning outcome assessments in the different STEM fields be updated in collaboration with relevant science and engineering associations. Also, given the paucity of data on post-graduate employment, the report suggests that much can be learned from further collection and analysis of data regarding post-graduate employment status.

Japanese STEM Education Policies

The strategy for developing human resource in science and technology put forth by the MEXT in 2015 entails three strategic directions. Strategic direction 1 aims to strengthen the education and research function of institutes of higher education. Within this direction, there are four priority issues: Priority 1 is to strengthen the professional leader development system; Priority 2 is to promote the global educational function; Priority 3 is to produce sustainable innovation in collaboration with regional industries and enterprises; and Priority 4 is to cultivate STEM-related human resources by reorganizing and rearranging the education and research functions of national university corporations. Strategic direction 2 has to do with more active utilization of women and working professionals in STEM fields. In concrete terms, the strategic direction is to develop STEM-related human resources at the elementary and secondary education levels and to increase the number of women and working professionals majoring in STEM fields. Strategic direction 3 is to promote collaboration among industries, government, and universities.

The 5th Science and Technology Basic Plan announced in 2016 reflects the Japanese government's strong resolve to promote science and technology innovation policies. In terms of higher education, the plan urges each institution to revise and redefine its function and mission. Accordingly, a greater than 4% increase in investment in research development in proportion with GDP is budgeted for the period between 2016 and 2020.

The research and development budgets of the majority of OECD countries, including the United States, Japan, France, Italy and Canada, have decreased relative to 2008 levels in all cases, except Korea between 2008 and 2015, and the United Kingdom between 2013 and 2014. Most countries are concerned about this decrease in R&D budgets, and this concern is reflected in their science and technology policies. Figure 1.1 presents the proportion of STEM graduates of 2015 in



* year of reference is 2014 and Data on Information and communication technologies are included in the other field

Fig. 1.1 Distribution of tertiary graduates in 2015, by field of study in selected OECD countries (*Source* The author made the figure based on OECD 2016 Data. *Education at a Glance 2017* based on the data of p. 72, https://read.oecd-ilibrary.org/education/education-at-a-glance-2017_eag-2017-en#page1)

tertiary education which includes, undergraduate, master's, and doctoral education in selected OECD countries. As is it shown in Fig. 1.1, whereas more than 40% of graduates of STEM in Korea, Germany, and United Kingdom, close to 40% of graduates of STEM in tertiary education in STEM in Japan and Australia. There are around 30% of graduates of STEM in tertiary education in the United States.

Whereas STEM students in Korea, Japan, and Germany tend to major in engineering, STEM students of England and Germany tend to major in sciences, mathematics, and computer science; the proportion of students majoring in such fields is the lowest in Japan. Also, the proportion of students majoring in medical sciences and social welfare is higher in most countries than in Japan. But many of students majoring in medical and social welfare in most countries concentrate on nursing and social welfare.

Twenty-First Century Learning Outcomes and STEM Education

In today's so-called knowledge-based society, there has been a shift worldwide from knowledge attainment-oriented teaching and learning to new educational methods. Traditional knowledge transmission-oriented teaching and learning is effective for acquiring basic skills, standardized skills, a certain amount of knowledge, and adaptability. However, there is widespread recognition that knowledge transmission-based and memorization based-learning is of limited value in terms of cultivating traits, such as diversity, creativity, sense of challenge, individuality, proactiveness, and leadership. It is often pointed out that the acquisition of practical and adaptive knowledge is closely associated with an active learning method.

The behaviors of speaking, writing, drawing connections, and applying learning enumerated by Chickering and Gamson (1991) are also outcomes shared by universal skills, integrative learning experiences, and creative thinking skills, which subsume (1) communication skills, (2) quantitative skills, (3) information literacy, (4) ability to think logically, and (5) problem-solving skills—i.e., skills found in Essential Learning Outcomes (ELO) and undergraduate academic abilities presented by the Association of American Colleges and Universities (AAC&U) in 2011. The direction of STEM education reform as guided by AAC&U emphasizes the cultivation of communication skills and cultural understanding for solving global issues. According to the guidelines of the Liberal Education and America's Promise (LEAP) initiative launched by AAC&U, STEM curricula should provide knowledge related to energy, air and water quality, global warming, and should provide real opportunities for students to analyze, practice, and actually implement solutions to problems. This perspective is closely associated with the possibility to show a solution based on the world and local culture. Hence, the participation of STEM students in study abroad programs becomes more important than ever. At the same time, the guidelines recognize that complicated issues affecting the world cannot be solved only with STEM expertise but also require ideas and approaches from various disciplines. As such, there is an increasing need for STEM education to include interdisciplinary programs involving the humanities and social sciences as well as arts. Integrated courses involving STEM and other disciplines are being developed at the general education level and courses related to design thinking are being encouraged at both lower and upper division levels. In fact, the PCAST 2012 action plan encourages action to be taken to increase opportunities for students to take courses involving both scientific research and design thinking in general education curricula in collaboration with NSF initiatives.

In Japan, interdisciplinary graduate programs combining STEM curricula with humanities and social sciences curricula have been developed through special funding from the government, and a number of STEM universities selected to take part in the Top Global University program promote study abroad programs for their students as opportunities to engage in multi- and intercultural exchange.

Engineering education in Japan has adopted the design thinking reform initiated by JABEE (Japan Accreditation Board for Engineering Education). When the JABEE was applying to become a member of the Washington Accord, JABEE received the criticism that Japanese engineering/design education is not strong. Since then, JABEE has encouraged member universities and programs to improve their engineering/design curricula based on the following criteria: (1) whether or not the curriculum/program establishes the designing ability goals to be obtained; (2) whether or not the students have opportunities to learn design thinking and problem-solving; and (3) whether or not the curriculum/program offers design thinking courses that present comprehensive challenges to students and cultivate diverse abilities.[2] It appears that efforts to reform engineering education in many countries have similar goals. That said, there is little past research that has focused on global competences required in STEM fields. In particular, there have been no studies on the relationship between twenty-first century skills and abilities (such as interdisciplinary knowledge and intercultural understanding) and STEM higher education. Figure 1.2 shows the result of self-reported evaluation for twenty-first century learning outcomes broken down by

[2] The contents referred to the results of interview with JABEE staffs.

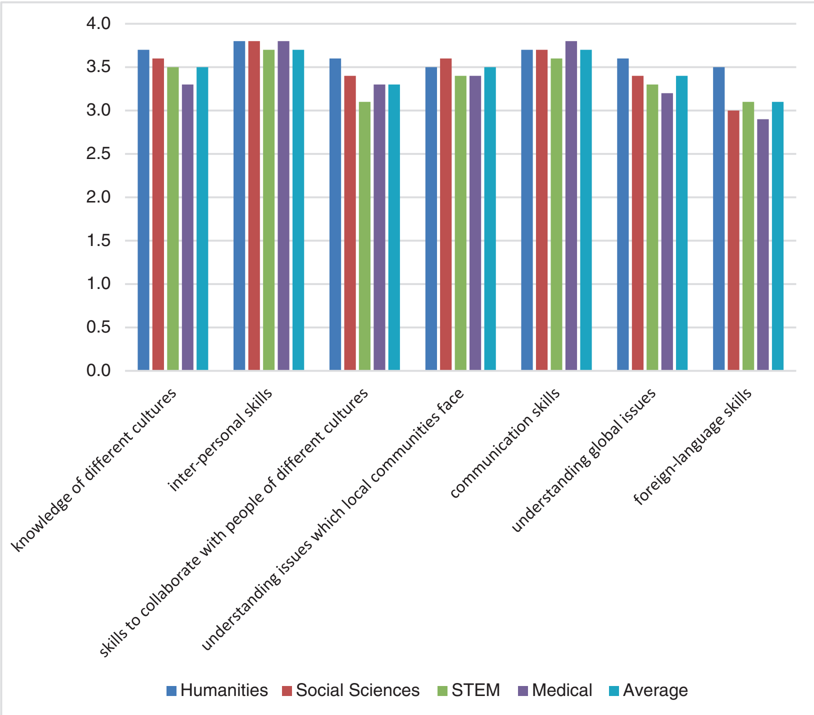


Fig. 1.2 Self-reported evaluation on twenty-first century's skills and abilities as learning outcomes by disciplines

field.[3] No substantial difference was observed among the four academic fields. However, students in STEM disciplines scored lower on "interpersonal skills" than students in other disciplines. STEM students tended to rate themselves especially lower on the skill "to collaborate with people of different cultures" than students in the humanities and social sciences. Also, STEM student rated themselves lower than average on "communication skills." From this, it appears that STEM students have a relatively harder time acquiring twenty-first century skills and abilities. Since STEM curricula in many countries are highly structured, which has to

[3]This data is based on our Japanese College Student Survey (JCSS) conducted in 2012. The sample included 5786 students at 26 four-year universities. 4.0 is maximum score.

do with the high level of expertise and skills required for mastery of the material, it is not easy to incorporate experiences that encourage students to act globally. This is a common challenge for all STEM fields. In the following section, we will examine Stanford University's Bing Overseas Studies Program (BOSP) as a case study.

Stanford University Bing Overseas Studies Program (BOSP)

Stanford University offers the study abroad program so-called Bing Overseas Studies Program. The Stanford University website of undergrad shows Study Abroad Overviews as a following:

> The Bing Overseas Studies Program (BOSP) offers the opportunity to study abroad while remaining enrolled at Stanford and is considered an integral part of the Stanford curriculum. The demographic breakdown of BOSP participants closely mirrors that of the entire Stanford population. Approximately 50 percent of each graduating class studies abroad on a BOSP program during their undergraduate career at Stanford. All BOSP programs offer direct Stanford credit for courses taught overseas that frequently count toward one or more majors. In addition, many BOSP courses fulfill Ways of Thinking/Ways of Doing Requirements (WAYS). Regular tuition applies, and financial aid continues. BOSP operates a variety of programs, including quarter length programs, internships and other opportunities.

https://undergrad.stanford.edu/programs/bosp/explore/study-abroad-overview

School of Engineering program at Stanford University offers a study abroad program as an opportunity for engineering students to acquire skills that will allow them to act globally. Therefore, engineering students utilize this BOSP program which offers quarter-length programs in Australia, Florence, Oxford, Berlin, Kyoto, Paris, Cape Town, Madrid, and Santiago.[4]

The purpose of the program is to provide engineering students with an opportunity to acquire not only knowledge and skills in a different cultural context but also to develop an international sense of behavior.

[4] https://undergrad.stanford.edu/advising/student-guides/can-engineers-study-abroad, accessed May 13, 2018.

When I talked with the staff of BOSP Kyoto program, the person explained that underlying the establishment of this program is Stanford University's recognition that the job of an engineer is internationally compatible and that many schools of engineering graduates, in fact, are stationed or work in foreign countries as consultants, managers, or engineers. Such jobs require both cultural and intercultural literacy. Thus, Stanford University regards the study abroad program as indispensable. Actually, the BOSP Kyoto program is located in Stanford Center in Doshisha University and participating students of both engineering students and other field students can take the Japanese classes in language, Japanese culture, and other several classes offered from Doshisha University and they have many opportunities to have internships in Japanese corporations through this program.

Conclusion

In the current globalized and knowledge-based society, universities throughout the world have been forced to become aware of their global ranking, which impacts the amount of research funding they can obtain, the number of foreign students they can attract, their international reputation, and their ability to receive national funding. In this context, STEM disciplines have received much attention worldwide. As a result, many countries, such as the United States, the United Kingdom, Australia, Singapore, China, and Japan have placed greater emphasis on science and technology policies. STEM education and the reform of STEM education at all levels, from K-12 to higher education, has become increasingly important. Many countries have adopted policies to increase the number of undergraduate and graduate students in STEM-related fields and to connect university research with industry to create foundations for future job markets. At the same time, in the globalized world, new issues whose resolution requires interdisciplinary knowledge and skills have emerged. It is expected that STEM education, especially engineering education, will have to be transformed in order to be able to deal with such issues. It is important that STEM fields be integrated with other fields, such as humanities, arts, and social sciences. Also, STEM students must acquire cultural and intercultural literacy if they are to work globally. However, STEM curricula around the world are highly structured and focused in a single discipline; as such, there is less flexibility to allow students to experience studying abroad and to get practical experience in local communities. Educational institutions around the world share the common challenge of how to transform highly structured curricula of STEM disciplines, including engineering, to include international experience.

References

AAC&U. 2011. *The Leap: Vision for Learning, Outcomes, Practices, Impact, and Employers' Views, Liberal Education & America's Promise*. Washington, DC: AAC&U.

AAC&U Cabinet Office. 2016. *The 5th Science and Technology Basic Plan*. Available online at http://www8.cao.go.jp/cstp/kihonkeikaku/5honbun.pdf. Accessed January 10, 2017.

Chickering, Arther W., and Zelda F. Gamson. 1991. *Applying the Seven Principles for Good Practice in Undergraduate Education*. San Francisco, CA: Jossey-Bass.

Freeman, Brigid. 2015. "Federal and State STEM Policies and Programmes Spanning Australian Education, Training, Science and Innovation." In *The Age of STEM: Educational Policy and Practice Across the World in Science, Technology, Engineering and Mathematics*, edited by Brigid Freeman, Simon Marginson, and Russell Tytler, 178–200. New York: Routledge.

House of Lords. 2012. *Higher Education in Science, Technology, Engineering and Mathematics Subjects*. London: The Authority of the House of Lords.

Ministry of Education, Culture, Sports, Science and Technology. 2015. *The Strategy of Developing Human Resource in Science and Technology*. Available online at http://www.mext.go.jp/component/a_menu/education/detail/__icsFiles/afieldfile/2015/03/13/1351892_02.pdf. Accessed January 10, 2017.

National Academies of Sciences, Engineering, and Medicine. 2016. *Developing a National STEM Workforce Strategy: A Workshop Summary*. New York: The National Academies Press.

Office of the Chief Scientist. 2014. *Science, Technology, Engineering and Mathematics: Australia's Future*. Canberra: Australian Government.

Organization of Economic and Co-operative Development (OECD). 2017. Education at Glance, 2017. *Education at a Glance 2017: OECD Indicators*. Available online at https://read.oecd-ilibrary.org/education/education-at-a-glance-2017_eag-2017-en#page1.

President's Council of Advisors on Science and Technology. 2010. *K-12 Education in Science, Technology, Engineering, and Math for America's Future*. Washington, DC: Executive Office of the President.

President's Council of Advisors on Science and Technology. 2012. *Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering and Mathematics*. Washington, DC: Executive Office of the President.

Senda, Yuici. 2013. "The Plan to Increase 1Million STEM Graduates: The US Strategic Planning of Science and Technology." *Science and Technology Movement*, January/February 4–26.

Stanford University, UNDERGRAD. Available online at https://undergrad.stanford.edu/advising/student-guides/can-engineers-study-abroad. Accessed May 13, 2018.

CHAPTER 2

STEM and the History of the University Ranking Movement: Contextualizing Trends in Methodologies and Criteria

William R. Stevenson III

Wherever universities exist, and for as long as they have existed, there have been debates over which schools are the most prestigious or which can boast the highest quality of learning. Nevertheless, it has only been over the past one hundred years that such conjecturing has given way to data-driven rankings. In the beginning, rankings included only a limited number of American universities and served primarily as a source of reference for a small group of scholars. More recently, enabled by technological advances, rankings have incorporated bigger data and used increasingly complex equations to rank institutions from around the world. The results have changed the culture of higher learning. Today, rankings not only affect prospective students, but they also impact university agenda and governmental policy. In particular, they have led to increased emphasis on research-intensive STEM fields, often at the

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*,
International and Development Education,
https://doi.org/10.1007/978-3-319-98666-1_2

expense of the social sciences and humanities. Yet, while recent rankings use more data and wield greater influence across the globe, they have changed little in terms of methodology, remaining captive to the same criteria that characterized such lists from the start. The following provides an overview of past rankings, focusing on the role of STEM fields in particular, with the goal of establishing a deeper and more contextualized understanding of the ranking movement and its current impact on higher education.

Men of Science and Their Universities

The modern ranking movement began at the turn of the twentieth century, appearing in connection with the publication of various articles and books that focused on the backgrounds of prominent individuals. To use the title of Alick Maclean's brief study, the common goal was to understand *Where We Get Our Best Men* (1900) and, in some cases, women. While authors such as Havelock Ellis in *A Study of British Genius* (1904) were hesitant to link education to success, concluding that great individuals "owe a remarkably small proportion of their learning to the established machinery of instruction" (p. 148), others were eager to connect intelligence or social prominence to learning. Of particular importance to the birth of university rankings was John Leonard's *Who's Who in America*. The original 1899 edition includes 8602 names of notable living Americans and opens with an "educational statistics" section in which Leonard argues that education is among the "especially prominent" characteristics shared by the successful men and women referenced in his study. Leonard, however, did not attempt to measure the connection between education and success. And, despite the urging of an unnamed "scientific man," for reasons of "time and space" he declined to include lists that would show which institutions had produced "the most eminent men," suggesting instead that the readers do their own calculations (p. xii).

Within a few years, psychologist and science advocate James McKeen Cattell (1860–1944) took up the challenge. He began by compiling a reference work entitled *American Men of Science*, which grew out of an earlier list created for the Carnegie Institution of Washington. The volume itself does not rank schools, but Cattell (1906, p. v) claimed that it was the first work to provide a "fairly complete survey of the scientific activity of a country at a given period," which could be "even more useful in academic circles than … *Who's Who in America*." The first edition of the work includes biographical sketches of over four thousand scientists from twelve designated fields. Cattell and his assistants selected the four thousand from roughly ten thousand questionnaires sent to persons believed to have "contributed to the advancement of pure science" based on their belonging to scientific societies, their contribution to scientific research and writing, or their inclusion in other lists such as *Who's Who in America* (pp. v–vi). Cattell then added a star to one thousand of the entries—a quarter of the listed scientists—whose work was thought to be "the most important" (p. vii). He selected these individuals by having ten leading scientists from each of the twelve fields arrange the names of persons within their field "in order of merit" (p. vii).

While Cattell's work is significant for its novel approach to determining the status of individual scientists, what makes *American Men of Science* of particular interest to the current rankings movement are two papers that he wrote in the process of creating the larger work. First, in a 1903 article for the *American Journal of Psychology*, Cattell took a select group of two hundred American psychologists and did a publication count to compare their influence with that of Europeans. In Cattell's words, "to compare our productivity with that of other nations, I have counted up the first thousand references in the index of the twenty-five volumes of the *Zeitschrift fur Psychologie*" (p. 327) and concluded that "it appears that each of our psychologists has on the average made a contribution of some importance only once in two or three years" (p. 328). Apart from highlighting an Atlantic divide that no longer exists, the study is notable for being one of the earliest uses of bibliometrics to establish academic hierarchy.

The second study appeared in *Science*, the official journal of the American Association for the Advancement of Science and a publication that Cattell personally owned.[1] In brief, the study took the one thousand distinguished scientists from the 1906 volume and calculated their number *and* list placement to compile a ranking of institutions based on "scientific strength." The top five results were Harvard, followed by Chicago, Columbia, John Hopkins, and Yale. Cattell made no pretense of having considered anything more than the production of scientific knowledge. He wrote that while "a university may conceivably have a

[1] Cattell also included the results of the study in the second edition (1910) of *American Men of Science*.

department consisting of men of moderate scientific standing, but of personal distinction and superior teaching ability … such men belong to the past rather than to the present generation." After all, though admittedly conjecture, Cattell argued that "scientific men of ability and character will be investigators, and there is a high correlation between these traits and teaching skill" (Cattell 1910, pp. 684–685).

Current research shows this conclusion to be wrong. In their often-cited study, Marsh and Hattie (2002) indicate that "teaching effectiveness and research productivity are nearly uncorrelated," and that "research performance does not provide a surrogate measure of teaching effectiveness, nor do measures of teaching effectiveness provide an indication of research productivity" (p. 635). Nevertheless, Cattell believed that scientific research should not only be the primary purpose of the university, but that it was the foundation for all of industrial civilization. "Science and its applications," he wrote, "should be the chief concern of a democratic nation that would preserve its democracy and advance the freedom and the welfare of its people" (Cattell 1922, p. 278). While few today would argue that research production should be the sole measure of a university, Cattell's studies pioneered several aspects of university assessment that continue to reverberate: his work was the first large study based on informed opinion gathered through a questionnaire, it was the first to focus on STEM field research, it was one of the first to use some form of bibliometrics and, finally, it was the first to be readily accessible. Its value, in Cattell's (1910, p. 688) own words, was to "show the advantage of statistics over general impressions."

Graduate School Rankings

Despite the originality of Cattell's study, he never updated his rankings. It would be another scientist, albeit one who had long abandoned his work as a chemist for administrative duties, to take the next step in university assessment. Raymond M. Hughes (1873–1958), president of Miami University, set out to evaluate and rank graduate programs from across the United States in the early 1920s (Hughes 1925). His goal was to produce a reference guide for Miami students looking to attend graduate school. Turning first to his university's faculty, he asked them to create a list of "distinguished national scholars" in 20 designated fields. He then sent each listed scholar a questionnaire, which became the basis of his assessment. He initially presented his study in a speech before the members of the Association of American Colleges and, according to Cartter (1966), "stirred up considerable interest, and no little criticism," but "presumably had an impact on that student generation" (p. 5).

Perhaps Hughes harshest critic was future university ranker Hayward Keniston (1883–1970). Writing a quarter century later, Keniston (1959) described Hughes' effort as being dependent on "highly subjective impressions" that were subject to the "halo of past prestige." The end result, according to Keniston, was a ranking of no "real validity" apart from providing a "fairly close approximation to what informed people think about the standing of the departments in each of the fields" (p. 117). Keniston, a well-known scholar of Romance languages, came out of retirement in the late 1950s to work as a consultant to the University of Pennsylvania, heading their effort to update Hughes' study. The goal was to determine the position of Pennsylvania's graduate programs relative to those at other leading schools.

Despite his criticisms of Hughes, Keniston followed a similar approach. The only significant difference is that he limited his survey to department chairs who, in his opinion, "by virtue of their office … know what is going on at other institutions" (p. 117). He asked them to rank graduate programs based on a combination of faculty reputation and perceptions of program quality. The results were then compiled to provide twenty-four departmental rankings. He then merged the lists to rank graduate programs in four general areas (biological sciences, humanities, physical sciences, and social sciences), and finally combined the data to produce an institution-wide ranking. Even while critical of Hughes' earlier study, Keniston chose to list his findings alongside the 1925 rankings to assess quality gains and losses over the previous quarter century. He concluded that several universities, primarily state schools, had noticeably improved while others, such as Chicago, had lost much of their status.

Less than a decade later, economist and vice-president of the American Council of Education, Allan M. Cartter (1922–1976), led a new study that set out to update earlier rankings and assess on a far broader scale the graduate programs of all "major universities" in the United States. His primary criticisms of earlier rankings, and of Keniston in particular, was that they relied too heavily on department chairs: a demographic that in Cartter's view tended to be older, more conservative, outdated in perception, and not necessarily the most informed or distinguished scholars in their field. He also argued that both Hughes and Keniston had failed "to separate measures of faculty quality from measures of educational quality" (Cartter 1966, p. 6). A valid survey, he thought, needed to make a clear distinction between the "scholarly reputation" of faculty and the value of a program in terms of the students' "educational experience" (p. 9).

Cartter's approach was to survey 4008 junior scholars, senior scholars, and department chairs representing 29 fields of study from 106 institutions, leading to an assessment of 1663 doctoral programs. His questionnaires distinguished between "quality of faculty" and "effectiveness of graduate program," resulting in a more nuanced ranking that, in his own opinion, was "as reliable a guide as one can devise in attempting to measure the elusive attribute of quality" (p. 9). Cartter was keenly aware of the subjective nature of university rankings. In fact, he opens his study by explaining that "in the final analysis the national reputation of a department or an institution is nothing more than an aggregation of individual opinions" (p. viii). As such, Cartter chose to limit his assessment to programs and, almost in passing, to five "general areas of study." He refused to combine scores to create a university-wide ranking, writing that such an effort would be arbitrary as it would involve "some judgement about how the various fields of study should be weighted" (p. 106).

Cartter's ranking was similar to those of Hughes and Keniston in its dependence on informed opinion. Where it differed, besides scale and its use of a more nuanced questionnaire, is that Cartter chose to go deeper in his analysis, choosing four of the twenty-nine fields (economics, English, political science, and physics) for a more detailed study that included bibliometrics. The method echoed the earlier efforts of Cattell, but rather than count the number of references made to scholarly works, Cartter initiated a method that is still used today. He selected major journals from each of the four fields (the number of journals varying with each field) and, looking at a four-year period, counted the number of articles, shorter communications, and book reviews published by the faculty of each institution. In addition, he tallied the number of books, textbooks, and edited volumes reviewed in the same journals and assigned each type of publication a designated weight. Taking into consideration the unique character of each discipline, Cartter and his team selected different weight ratios for each of the four fields. Unlike many ranking systems today that use bibliometrics as a core or sole indicator, assessing universities based on rates of quality publication, Cartter only used bibliometrics to examine the correlation between the results of his ranking and the production of scholarship (pp. 78–105). In the field of economics, for example, there was a clear correlation between the strengths of a program and publication rates. In the field of English, however, Cartter found the correlation to be far less pronounced, with the faculty of weaker programs often producing work at a rate that would put them on par with scholars from higher ranked schools (pp. 80, 88).

According to Gourman (1977), "the academic community's response to the Cartter report was overwhelming," inspiring "widespread comment and critique" (p. 7). Within five years, 26,000 copies were distributed, which was followed by a second study headed by the American Council on Education in 1970 that used the same basic methods (Roose and Andersen 1970). In addition, even though Cartter refused to turn his assessment of graduate programs into an institution-wide ranking, others quickly did so using the results of his study. Horace Magoun (1907–1991), for example, published an institution-wide ranking within the same year, justifying his article on the grounds that "such syntheses are of value today because of the extent to which activities related to graduate education have come to determine the intellectual and economic well-being of the communities and regions in which graduate schools are situated." Continuing, he writes, "In our contemporary society, many extra-mural groups and agencies are interested in the over-all standings of universities and their divisions" (Magoun 1966, p. 483). Magoun does not specify any "groups" or "agencies," but the implication is clear: long before the current proliferation of university rankings, long before schools began to aggressively look for ways to improve their international standing, the link between "economic well-being" and the "overall standing of universities" was being established.

The Ranking Explosion

While Cartter's study reached a far broader audience than that of Cattell, Hughes, or Keniston, all four rankings were produced by academics for academics. It was only the involvement of media corporations and major publishing houses that eventually resulted in university assessment going mainstream. The *Chicago Tribune* was possibly the first newspaper to publish a university ranking, listing the best ten undergraduate programs in a widely discussed piece by Chesly Manly. Although based on a survey of prominent educators, the criteria for "best" was largely left to respondents (Stuit 1960, p. 375). Meanwhile, the postwar surge in college enrollment rates created a market for college guidebooks. Among the earliest was the College Entrance Examination Board's *Annual Handbook*, but it was Barron's *Profiles of American Colleges* (1964 to present) that began to rank the universities according to categories of "most competitive" to "noncompetitive." James Cass and Max Birnbaum's *Comparative Guide to American Colleges* (Harper and Row, 1964–1991) and *Peterson's Annual Guide to Undergraduate Study* (first published in 1970, and currently titled *Peterson's Four-Year Colleges*) followed a similar pattern. While the publications surely encouraged prospective students to think of universities in hierarchal terms, their assessments were admittedly subjective. Cass and Birnbaum, for example, wrote that their categories were "not a measure of the overall quality of colleges, which are far too complex to be ranked by simple statistical data" (1989, 14 ed., p. x).

In 1983, *U.S. News & World Report* began publishing a biennial review of schools that contained both guidebook elements and a straightforward institutional ranking. Although the methods were initially dubious, by the end of the decade the company was producing an annual standalone issue, "America's Best Colleges," that used various combinations of survey data along with previously unreleased information provided by the institutions. The magazine was not the first to combine criteria, but it pioneered the use of "inside" data that gave its results an aura of authority. According to Usher (2017), universities "could still criticize the use of survey data in the rankings or the weighting of the different indicators within the rankings, … [but] the debate was no longer really about whether multi-indicator rankings were measuring quality or not; the debate accepted that assumption, and moved on to the question of whether the methodology was correct."

Using their marketing know-how, *U.S. News & World Report* turned the study of university assessment into a lucrative business. With everyday Americans hungry to learn which universities topped each years' lists, traditional powerhouses, such as Stanford, Cornell, and Yale began to "play the rankings game" by looking for ways to improve their status (Machung 1998). Rankings were no longer a mere measurement of university quality, they were now shaping the direction of higher education policy.

The "America's Best Colleges" approach quickly became the standard, and a model for companies and organizations across Europe, Asia, and the Americas. Over the ensuing years, *Maclean's* in Canada, *The Times* and *The Guardian* in England, *Asahi* and *Yomiuri* in Japan, *Der Spiegel* in Germany, and others created their own national rankings, experimenting with different combinations of indexes. And, with top universities becoming increasingly global in scope, it was only a matter of time before the rankings became global in scale. By the early twenty-first century, international student recruitment had become widespread, which according to Harvey (2008), served as the prime incentive for creating international university rankings. Shanghai's Jiao Tong University led the way in 2003, resulting in the current Academic Ranking of World Universities (ARWU; est. 2009). QS World University Rankings (est. 2004) came next, followed by the Dutch CWTS Leiden Ranking (est. 2007), the Thomas Reuters' *Times Higher Education* (*THE*) rankings (est. 2010), the Saudi Arabian Center for World University Rankings (CWUR) rankings, and, among others, *U.S. News & World Report* Best Global Universities rankings (est. 2014).

The global rankings market is now flooded with competitors, and their growing influence has led to a sense of unease among many in academia. Much of the worry is based on the tendency of rankings to assess what some believe to be a limited picture of higher education. In particular, critics are quick to point at assessments based on citation indexing services, namely Elsevier's Scopus and Thomson Reuter's Web of Science, that favor STEM fields with their high rates of publication. Those in the humanities in particular, "see this phenomenon as a colonization of their domain through a system that has mainly been applied (and probably can only be applied) in the positive sciences" (Loobuyck 2009, p. 209).

While online indexing services are a recent development, university rankings have never gone unchallenged. In 1910, during the same year that Cattell published the first analytical ranking of colleges, the American Association of Universities asked historian-turned-administrator Kendrick Babcock to assess the quality of higher education. His rankings, leaked to the press, caused such an uproar (particularly among those affiliated with schools that failed to make an impression) that President William Taft—and later Woodrow Wilson—banned their publication (Webster 1986). Similarly, in 1957, when the *Chicago Tribune* became the first newspaper to produce a list of best undergraduate programs, Northwestern University's school paper complained that the listing had "done a lot of harm" and may have "damage[d] them materially" (*The Stanford Daily*, 1957). Finally, in a critique of his own pioneering work, Allan Cartter wrote that, “No single index … nor any combination of measures is sufficient to estimate adequately the true worth of an educational institution” (Cartter 1966, p. 4). While debates continue as to which measures are the most reliable or relevant, Cartter’s observations remain as pertinent today as they were 50 years ago: “In an operational sense,” he wrote, “quality *is* someone’s subjective assessment, for there is no way to objectively measuring what is in essence an attribute of value” (Cartter 1966, p. 4).

Conclusion

For over a century universities have been assessed and ranked according to outcome-oriented methodologies, including the use of bibliometrics and reputation surveys. STEM fields have been core to these indexes from the start. In fact, the first impression of a hundred-year survey of university rankings is that remarkably little has changed. Of the limited number of new approaches, the most notable was likely OECD’s Assessment of Higher Education Learning Outcomes (AHELO). Conducted in 2012 as a “feasibility study,” it looked to scientifically assess “what students in higher education know and can do upon graduation” (http://www.oecd.org). Seen as a threat to more traditional forms of assessment, the OECD announced in 2015 that the project would be placed on hold (Morgan 2015). In short, for generations, there has been surprising consistency in the general methodologies used to evaluate schools. It is only in the details that differences between past and current systems begin to emerge, and it is only in distinct emphases that competing systems of ranking produce their various results.

What has changed, and what makes the current world rankings movement cause for concern is its seemingly uninhibited growth in scale and influence. World rankings today receive nearly universal coverage, eliciting responses from every corner of the globe. The University of Nairobi’s “development studies” program appears on a QS ranking and the school celebrates for being included in the “top 100 universities across the globe” (QS Rankings 2016); Shanghai loads the top of their rankings with American universities and contributes to a surge of international students that brings more than thirty-five billion dollars annually into the US economy; London’s *THE* ranking demotes the University of Malaya and results in politicians calling for the resignation of the Minister of Education (*The Malaysian Times* 2014); meanwhile, the Russian government, like many others, recently established a massive grant aimed at getting five national universities ranked among the top 100 in the world. Today, the implications of university rankings go far beyond past systems of assessment. No longer just a reference for prospective students or administrators, rankings are now center to a high-stakes competition, an "academic arms race" (Rhoads et al. 2014) that is fought on a global scale.

Despite the widespread belief that world rankings have too much influence, or that existing rankings compromise the educational role of universities by placing too much emphasis on STEM field research, there is no immediate alternative to the current system. Nevertheless, in agreement with Altbach, as "the inevitable logic of globalization make them a permanent part of the 21st-century … [t]he challenge is to understand their nuances, problems, uses—and misuses" (2012, p. 31). The tendency to lump all schools together, irrespective of contexts, emphases, or stated purposes, and the impulse to place more value on statistically friendly research production than on the more opaque measurements of quality instruction are particularly worrisome. All of these trends—compounded by the economic implications of a knowledge economy—have led to an increased emphasis on STEM fields. Nevertheless, as shown, the first significant ranking of universities was, in fact, a STEM field ranking. For better or worse, the developed world has been moving toward a STEM-oriented future for generations and, as is becoming more evident, the rate of acceleration has outpaced the ability of non-STEM fields to adapt. This was the dilemma that John Plumb described in his 1964 *The Crisis in the Humanities*, but which a half-century of developments have failed to remedy. Academic fields that are underrepresented in university rankings and, by implication, have less to offer in a knowledge economy, are today struggling to maintain their place in higher learning; in some cases, they are frantically looking for students to justify their continued existence. Cartter began his 1966 study by ranking programs within the humanities, leaving STEM fields for the end. Since his writing, enrollment rates for the humanities has dropped by half (*Harvard Magazine* 2013). Meanwhile, the most recent Nobel prize for literature—the only Noble marked for a non-STEM field—went to a guitar-wielding folksinger who aptly prophesied that "the times, they are a-changing."

References

"Addressing a Decline in Humanities Enrollment." 2013. *Harvard Magazine*, June 6. http://harvardmagazine.com.

Altbach, Philip G. 2012. "The Globalization of College and University Rankings." *Change: The Magazine of Higher Learning* 44 (1): 26–31.

Cartter, Allan M. 1966. *An Assessment of Quality in Graduate Education*. Washington, DC: American Council on Education.

Cass, James, and Max Birhbaum. 1989. *Peterson's Guide to Four-Year Colleges*, 14th ed. Princeton, NJ: Peterson's Guides.

Cattell, J. Mckeen. 1903. "Statistics of American Psychologists." *American Journal of Psychology* 14: 310–328.

———, ed. 1906. *American Men of Science: A Biographical Directory*. New York: The Science Press.

———. 1910. "A Further Statistical Study of American Men of Science." *Science* 32 (828): 672–688.

———. 1922. "The Organization of Scientific Men." *The Scientific Monthly* 14 (6): 568–578.

Gourman, Jack. 1977. *The Gourman Report: A Rating of Undergraduate Programs in American and International Universities*. Los Angeles: National Education Standards.

Harvey, Lee. 2008. "Rankings of Higher Education Institutions: A Critical Review." *Quality in Higher Education* 14 (3): 187–207.

Hughes, Raymond M. 1925. *A Study of the Graduate Schools of America*. Oxford, OH: Miami University.

Keniston, Hayward. 1959. *Graduate Study and Research in the Arts and Sciences at the University of Pennsylvania*. Philadelphia: University of Pennsylvania Press.

Leonard, John W., ed. 1899. *Who's Who in America: A Biographical Dictionary of Living Men and Women of the United States, 1899–1900*. Chicago: A. N. Marquis & Company.

Loobuyck, Patrick. 2009. "What Kind of University Rankings Do We Want?" *Ethical Perspectives* 16 (2): 207–224.

Machung, Anne. 1998. "Playing the Rankings Game." *Change* 30 (4): 12–16.

Magoun, Herbert W. 1966. "The Cartter Report on Quality in Graduate Education: Institutional and Divisional Standings Compiled from the Report." *Journal of Higher Education* 387 (9): 481–492.

Marsh, Herbert W., and John Hattie. 2002. "The Relation Between Research Productivity and Teaching Effectiveness." *Journal of Higher Education* 73 (5): 603–641.

Morgan, John. 2015. "OECD's Ahelo Will Fail to Launch." September 21. https://www.timeshighereducation.com.

"'Muhyiddin Is the One Should Resign', Slams Kit Siang." 2014. *The Malaysian Times*, June 30. http://www.themalaysiantimes.com.

"QS Rankings Place University of Nairobi Among Top 100 Universities Across the Globe." March 23, 2016. http://mombasa.uonbi.ac.ke.

Rhoads, Robert A., Shuai Li, and Lauren Ilano. 2014. "The Global Quest to Build World-Class Universities: Toward a Social Justice Agenda." *New Directions for Higher Education*. 168 (Winter): 27–39.

Roose, Kenneth D., and Charles J. Andersen. 1970. *A Rating of Graduate Programs*. Washington, DC: American Council on Education.

Stuit, Dewey B. 1960. "Evaluations of Institutions and Programs." *Review of Educational Research* 30 (4): 371–384.

"Tribune's College Ratings Cause Controversy." 1957. *The Stanford Daily*, 131 (52) (May 7).

Usher, Alex. 2017. "A Short Global History of Rankings." In *Global Rankings and the Geopolitics of Higher Education*, edited by Ellen Hazelkorn (pp. 23–53). London and New York: Routledge.

Webster, David S. 1986. *Academic Quality Rankings of American Colleges and Universities*. Springfield, IL: C. C. Thomas.

CHAPTER 3

STEM and Underrepresented Populations: What's at Stake

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Today, STEM fields are central to the growth and development of modern universities because many believe they provide the greatest returns on investment for stakeholders at the individual, institutional, national, and international level. At the individual-level, students and their families associate STEM fields with high-paying, high-growth jobs in the technology sector. Although "classic" professional fields, such as business, law, and medicine have retained their prestige, recent surveys have shown that careers associated with STEM fields have reached the same level of prestige, an impressive development over a relatively short period of time (Zhou 2005). At the institutional level, colleges and universities are reliant on STEM fields for their overall fiscal well-being because revenue from external sources dwarfs that from all other subject concentrations outside of medicine. This reliance is especially true for countries grappling with decreased government expenditures for publically funded institutions of higher learning (Ehrenberg et al. 2003).

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*,
International and Development Education,
https://doi.org/10.1007/978-3-319-98666-1_3

At the national level, STEM figures prominently in government policy (Breiner et al. 2012). Although the level of funding fluctuates from one political administration to another, many governments maintain explicit policies regarding science and technology and view both as central components of national security. Furthermore, many modern countries maintain bureaucratic agencies that exist independent from any specific administration (something not always true of non-STEM fields) whose sole focus is the development and promotion of STEM (van Langen and Dekkers 2005). At the international level, STEM fields have been at the forefront of efforts to increase the circulation of ideas, technology, and scholars across boundaries. In addition, international agreements between nations or supranational organizations (the Bologna Process is one such example) support various deals to maintain international scientific standards, massive cooperative technological/infrastructure projects, and the mutually beneficial training of students within STEM fields (Ravinet 2008).

However, the ascendancy of STEM fields in the academy and beyond is not without controversy. Modern universities tend to espouse egalitarian principles regarding the full inclusion and representation of all social groups within the academic community. This rationalization of inclusion rhetoric, whether actually enacted or enforced at any individual campus, means that universities are compelled to respond whenever individuals or groups make public claims of exclusion or discrimination against the university (Tierney and Chung 2002). The increased attention and funding allocated to STEM fields also come with a measure of increased scrutiny as to whether those same STEM fields are perpetuating inequality within and between universities. A small handful of elite universities receive the vast majority of external grants and government funding for STEM research, which often renders less-prestigious teaching-focused institutions unable to provide up-to-date facilities or training (Collins 1979; Davies and Zarifa 2012; Marginson 2016). Even at institutions with strong STEM offerings, there are high levels of attrition among prospective STEM majors (Mervis 2010; Watkins and Mazur 2013). Students pushed out of STEM majors are often individuals from marginalized groups within society (Chen 2013). And even when students manage to exit with a STEM major in hand, they often find that the skills they learned in the classroom are not always entirely in sync with the skills demanded within the labor force (Atkins 1999; Casner-Lotto and Barrington 2006).

This chapter examines the current situation of three categories of groups typically underrepresented within STEM fields in the United States: Women, ethnic/racial minorities, and the economically disadvantaged. Although the aforementioned groups do not face all the same obstacles toward greater inclusion within STEM fields, the central features of their struggle are similar in that they map directly onto inequality that these marginalized groups face in US society at large. The recent history of these underrepresented groups within STEM fields in the United States shows that, despite tremendous gains made by each group, the goal of full inclusion is still unfulfilled. I argue that each of these groups must be considered in any discussion about the relationship between STEM fields and university rankings because a failure to do so will ensure greater disparities and less inclusion within future iterations of the academy.

Women and STEM

Women have faced several significant barriers to inclusion within STEM fields over the course of US history. First and foremost, until the latter half of the twentieth century, most women were barred (either by law or custom) from admission to most American universities where STEM research was conducted. Colleges and universities that primarily educated women during this earlier period tended to focus on teacher training, secretarial skills, and a broad category of homemaker tasks that all women of social standing were expected to master (collectively known as the "domestic arts"). Globally, women have made tremendous strides in terms of college enrollments (Jacobs 1996). In fact, women now account for the majority of recent university graduates in most economically advanced countries (Charles and Bradley 2002; Buchmann and DiPrete 2006). However, women remain underrepresented within STEM fields in nearly every country in the world. What accounts for this continuing disparity?

Most scholars who study gender inequality within STEM identify issues with both the pipeline of students and the culture within STEM as being largely responsible for the underrepresentation of women. The term "pipeline" refers to the supply of students who would potentially become majors within STEM fields (Espinosa 2011). These potential STEM students need a relatively strong background in math and science in high school as well as an awareness of individual STEM fields and an eagerness to embark on a major within the area. Although girls typically outperform boys in all subject areas in high school, girls are less likely to rate their own performance in math and science as particularly strong (Correll 2001). This is often attributable to the popular depiction of both subjects as male domains. When faced with a stereotype and weak outside reinforcement of girls' competence within math and science, many otherwise well-prepared and qualified girls drift away from upper-level math and science courses later in high school or early in college (Nassar-McMillan et al. 2011; Mann and DiPrete 2013). Thus, the pipeline of women into STEM fields within college is much smaller than it could or should be. Women who do manage to persist within STEM fields often find that the culture within most departments and programs is ill-equipped to support the full inclusion of women within their disciplines. Many women in STEM fields report receiving less formal and informal mentorship than their male peers, getting less credit for their contributions, and feeling uncomfortable with the macho culture of labs and collaborative work environments (Xu 2008; Riegle-Crumb et al. 2012). Furthermore, several women report having to deal with repeated and unwanted romantic attention from colleagues and advisors. While some of these overtures only make for short-term awkwardness, others can escalate into sexual harassment or sexual assault. When women speak out about gender inequality in STEM, some face accusations of being overly sensitive or imagining inequality where none exists. In the most extreme cases, some women are ostracized by members of their department or pushed out of the discipline altogether. Finally, the limited number of STEM fields or subfields with more equitable gender representation and treatment (such as biology and archeology) tend to have fewer employment opportunities and pay less compared to more male-dominated fields and subfields (England and Li 2006).

Advocacy groups, educators, and even some universities have intervened over the past few decades to tackle the pipeline and culture problems that contribute to the gender disparities in STEM fields. Science and math enrichment programs for girls in secondary and even primary school have shown promising results in developing positive images of women as scientists, engineers, and mathematicians. Several social and traditional media campaigns have focused on promoting the visibility of successful women within the STEM field at all stages. More thorough application and enforcement of anti-discrimination laws have also provided better safeguards against the harassment and marginalization of women within many STEM fields at the university level. However, these above measures have not diffused evenly across all countries.

Racial and Ethnic Minorities and STEM

Racial and ethnic minorities are generally a very heterogeneous group, each with their own experiences surrounding higher education. The term "ethnic/racial minority" arose out of various movements for greater social and economic inclusion and political representation in the United States during the latter half of the twentieth century. The "minority" portion of the phrase refers to the fact that individuals under this designation are not from the ethnic/racial group in the numerical majority within a society. However, the broader political aim of the term was to foster a sense of common cause among many seemingly disconnected ethnic and racial groups.

Most ethnic and racial minorities, like women, were barred admission (either by law or by custom) to many of the more prestigious American colleges and universities where most STEM research occurred. Those who were granted admission were subject to strict quotas and were often still effectively barred from certain programs or academic facilities. Some countries (such as Australia, Canada, India, Japan, and the United States) maintained separate college facilities for certain racial or ethnic minorities, which usually received inferior funding and had inferior facilities to conduct STEM research. The very same political struggles that created the term "ethnic and racial minority" during the middle of the twentieth century were also responsible for ending legal prohibitions against the admission of ethnic and racial minorities.

It is often difficult to talk broadly of ethnic and racial minorities in STEM fields during the current era because outcomes both between and within different ethnic and/or racial groups have diverged greatly since the end of legal segregation in higher education. In the case of the United States, Asian- and Jewish-Americans generally have high rates of involvement within STEM fields relative to native-born American whites, while African-, Native-, and Latino-Americans generally have lower rates of STEM field involvement relative to native-born American whites. However, these general trends of STEM involvement mask within-group disparities that are evident when you disaggregate individual ethnic groups from larger racial or pan-ethnic categories. For instance, college attendance rates (let alone STEM field involvement) are particularly low for native-born Filipino-, Cambodian, Laotian-, and Hmong-Americans when compared with other Asian ethnic groups and native-born white Americans. Conversely, Cuban-Americans and the native-born children of Sub-Saharan African immigrants have relatively high college attendance rates and STEM field involvement compared to native-born white Americans. In general, ethnic and racial minorities in any country who have endured long legacies of economic and social exclusion or who entered a country en masse without significant educational credentials or economic resources are likely to have low rates of college attendance and thus a lower probability of STEM field involvement. This problem underrepresentation of ethnic and racial minorities in STEM is even more pronounced in countries without free and universal access to quality education or government programs designed to provide greater access to resources for the underprivileged.

Ethnic and racial minorities also face pipeline and culture issues associated with enrolling and succeeding in STEM majors. Although there is a great deal of heterogeneity among ethnic and racial minorities, the majority who do attend college are likely to come from backgrounds without much exposure to individuals working in STEM careers. Social science research shows a strong association between major choice and prior experience with individuals from the subject area of the selected major (Pascarella and Terenzini 2005; Porter and Umbach 2006). Without this access, ethnic and racial minorities are less likely to know of opportunities within STEM or to have a clear sense of how to navigate an academic program within the STEM fields. Furthermore, underprivileged ethnic and racial minorities who do manage to enroll are at an elevated risk for dropping STEM majors due to either poor preparation in high school and/or lack of advising support during their undergraduate studies (Tyson et al. 2007). The positive role of advising and mentoring in retaining ethnic and racial minorities in STEM majors cannot be overstated. Ethnic and racial minorities often must confront pervasive negative stereotypes related to their scholastic aptitude. These negative stereotypes are often exacerbated within STEM fields, where the dominant narrative constructs competence as innate characteristic and prevailing images of successful scientists, engineers, and mathematicians do not look like the majority of racial and ethnic minorities (Riegle-Crumb and King 2010).

There are several successful strategies aimed at increasing both the pipeline and the general well-being of ethnic and racial minorities within STEM fields. Similar to efforts with women, advocacy groups, educators, and some universities have instituted various enrichment and support programs aimed at developing awareness of and competence in STEM-related fields for underprivileged ethnic and racial minorities in primary and secondary schools. A number of colleges and universities have piloted bridge programs through which successful ethnic and racial minority high school students can enroll in college courses while still enrolled in high school. These pipeline measures increase subject-area knowledge within STEM fields before students become undergraduates, and create familiarity with practical aspects of STEM fields, thus bolstering confidence. A number of research universities have developed additional bridge programs designed to identify and recruit promising STEM majors in colleges and universities that primarily serve ethnic and racial minorities. This is of crucial importance because the majority of ethnic and racial minorities attend such institutions and may lack the sort of extensive social network necessary to provide opportunities for graduate study at elite research universities.

The Economically Disadvantaged and STEM

Individuals who are economically disadvantaged come from households without access to substantial financial resources. Although it is impossible to determine an absolute measure across all countries, most national and local governments maintain specific criteria that define who is considered economically disadvantaged. Most governments define economically disadvantaged households as those that are below or in close proximity to a certain level of total household income. Some, however, take into account enrollment in certain government-sponsored programs (such as food or medical assistance) to determine economic disadvantage. Some of the more common social issues associated with economic disadvantage are chronic unemployment, mental or physical disability, chronic illness, substance abuse, severe income inequality, and single parenthood. Numerically, children under the age of 18 make up the largest share of the economically disadvantaged. Often, economic disadvantage is intergenerational: Individuals born into economically disadvantaged families are likely to remain economically disadvantaged throughout the duration of their life.

One of the most effective ways of disrupting the intergenerational cycle of economic disadvantage is through higher education (Torche 2011). Individuals who obtain college degrees are much less likely to experience economic disadvantage later in life. However, individuals who grow up in economically disadvantaged households must overcome substantial hurdles just to attend college. First, and foremost, economically disadvantaged children in the United States usually attend underfunded secondary schools that do not always offer college-preparatory courses. Among the classes not typically offered at underfunded schools are advanced science and mathematics courses necessary to declare a STEM major upon arrival in college. In addition, economically disadvantaged students are often placed on or guided to vocational or technical tracks during secondary school that preclude entrance into colleges or universities with STEM majors. These factors alone would constrain the pipeline of economically disadvantaged students who are eligible to study within STEM fields in the United States (MacPhee et al. 2013).

Even when economically disadvantaged students manage to complete the advanced coursework necessary to declare a STEM major, financial issues can make attending college or majoring in STEM all but impossible. Students from economically disadvantaged households often feel obligated to forgo college and work full-time to contribute to family expenses. For those who do not feel such an obligation, fees associated with university attendance can be prohibitive. Moreover, the majority of economically disadvantaged students who do enroll in university are more likely to select majors directly associated with a vocation. STEM majors, which often include theoretical and abstract coursework, can seem disconnected from the career choices of many economically disadvantaged students.

Much like those for women and ethnic and racial minorities, practical solutions for increasing the number of economically disadvantaged students in STEM majors rest on improving both the pipeline and culture surrounding STEM. Advocate groups and universities have increased economically disadvantaged STEM majors through sponsoring summer and after-school enrichment programs. These programs are designed to increase student knowledge of STEM fields and preparedness for the prerequisite coursework necessary to major in a STEM field. Furthermore, many research universities with high endowments now offer drastically reduced or free tuition and board for high-achieving economically disadvantaged students. While not solely focused on prospective STEM majors, these measures increase the number of economically disadvantaged students who attend such schools and, when coupled with the previously mentioned enrichment programs, can increase the number of STEM majors. As for the culture on campus, economically disadvantaged students have continued to advocate for more programming and recognition of their status on college campuses. The result has been more programs focused on supporting and retaining economically disadvantaged students once they arrive on campus, thus increasing the probability of retaining economically disadvantaged STEM majors.

Working Toward the "Best-Case" Scenario

Although full inclusion within STEM fields is unlikely in the near future, underrepresented groups have made substantial strides toward this outcome in the United States. These gains were realized through sustained and long-term struggles on the part of underrepresented individuals and groups that advocated on their behalf. Eventually, academic institutions themselves formulated policies to reduce inequality within all academic fields and increase both the pipeline and retention of underrepresented groups. These measures are yet to have the desired effect, but they are crucial to eventually realizing the "Best Case" scenario of eliminating inequality within STEM fields.

The United States is not exceptional in this regard. Many other countries have developed policies and practices aimed at improving access and outcomes for underrepresented populations in STEM fields and beyond. It is imperative that the issue or representation and equality remain at the forefront of any discussions of university rankings and STEM. To do otherwise risks moving backward toward greater inequality, an outcome that is antithetical to the larger mission of academic institutions to spread knowledge and opportunity as broadly as possible.

References

Atkins, M. J. 1999. "Oven-Ready and Self-Basting: Taking Stock of Employability Skills." *Teaching in Higher Education* 4 (2): 267–280.

Breiner, Jonathan M., Shelly Sheats Harkness, Carla C. Johnson, and Catherine M. Koehler. 2012. "What Is STEM? A Discussion About Conceptions of STEM in Education and Partnerships." *School Science and Mathematics* 112 (1): 3–11.

Buchmann, Claudia, and Thomas A. DiPrete. 2006. "The Growing Female Advantage in College Completion: The Role of Family Background and Academic Achievement." *American Sociological Review* 71 (4): 515–541.

Casner-Lotto, Jill, and Linda Barrington. 2006. *Are They Really Ready to Work? Employers' Perspectives on the Basic Knowledge and Applied Skills of New Entrants to the 21st Century US Workforce.* Washington, DC: Partnership for 21st Century Skills.

Charles, Maria, and Karen Bradley. 2002. “Equal but Separate? a Cross-National Study of Sex Segregation in Higher Education.” *American Sociological Review* 67 (4): 573–599.

Chen, Xianglei. 2013. *STEM Attrition: College Students’ Paths into and Out of STEM Fields. Statistical Analysis Report. NCES 2014-001*. Washington, DC: National Center for Education Statistics.

Collins, Randall Alfred. 1979. *The Credential Sociology: An Historical Sociology of Education and Stratification*. New York, NY: Academic Press.

Correll, Shelley J. 2001. “Gender and the Career Choice Process: The Role of Biased Self-Assessments” *American Journal of Sociology* 106 (6): 1691–1730.

Davies, Scott, and David Zarifa. 2012. “The Stratification of Universities: Structural Inequality in Canada and the United States.” *Research in Social Stratification and Mobility* 30 (2): 143–158.

Ehrenberg, Ronald G., Michael J. Rizzo, and George H. Jakubson. 2003. *Who Bears the Growing Cost of Science at Universities?* Ithaca, NY: Cornell Higher Education Research Institute.

England, Paula, and Su Li. 2006. “Desegregation Stalled: The Changing Gender Composition of College Majors, 1971–2002.” *Gender & Society* 20 (5): 657–677.

Espinosa, Lorelle. 2011. “Pipelines and Pathways: Women of Color in Undergraduate STEM Majors and the College Experiences That Contribute to Persistence.” *Harvard Educational Review* 81 (2): 209–241.

Jacobs, Jerry A. 1996. “Gender Inequality and Higher Education.” *Annual Review of Sociology* 22 (1): 153–185.

MacPhee, David, Samantha Farro, and Silvia Sara Canetto. 2013. “Academic Self-Efficacy and Performance of Underrepresented STEM Majors: Gender, Ethnic, and Social Class Patterns.” *Analyses of Social Issues and Public Policy* 13 (1): 347–369.

Mann, Allison, and Thomas A. DiPrete. 2013. “Trends in Gender Segregation in the Choice of Science and Engineering Majors.” *Social Science Research* 42 (6): 1519–1541.

Marginson, Simon. 2016. “The Worldwide Trend to High Participation Higher Education: Dynamics of Social Stratification in Inclusive Systems.” *Higher Education* 72 (4): 413–434.

Mervis, Jeffrey. 2010. “Better Intro Courses Seen as Key to Reducing Attrition of STEM Majors.” *Science* 330 (6002): 306.

Nassar-McMillan, Sylvia C., Mary Wyer, Maria Oliver-Hoyo, and Jennifer Schneider. 2011. “New Tools for Examining Undergraduate Students’ STEM Stereotypes: Implications for Women and Other Underrepresented Groups.” *New Directions for Institutional Research* 152 (2011): 87–98.

Pascarella, Ernest T., and Patrick T. Terenzini. 2005. *How College Affects Students*. Edited by Kenneth A. Feldman. Vol. 2. San Francisco, CA: Jossey-Bass.

Porter, Stephen R., and Paul D. Umbach. 2006. "College Major Choice: An Analysis of Person–Environment Fit." *Research in Higher Education* 47 (4): 429–449.

Ravinet, Pauline. 2008. "From Voluntary Participation to Monitored Coordination: Why European Countries Feel Increasingly Bound by Their Commitment to the Bologna Process." *European Journal of Education* 43 (3): 353–367.

Riegle-Crumb, Catherine, and Barbara King. 2010. "Questioning a White Male Advantage in STEM Examining Disparities in College Major by Gender and Race/Ethnicity." *Educational Researcher* 39 (9): 656–664.

Riegle-Crumb, Catherine, Barbara King, Eric Grodsky, and Chandra Muller. 2012. "The More Things Change, the More They Stay the Same? Prior Achievement Fails to Explain Gender Inequality in Entry into STEM College Majors Over Time." *American Educational Research Journal* 49 (6): 1048–1073.

Tierney, William G., and Jack K. Chung. 2002. "Affirmative Action in a Post-Hopwood Era." In *The Racial Crisis in American Higher Education, Revised Edition—Continuing Challenges for the Twenty-First Century*, edited by William A. Smith, Philip G. Altbach, and Kofi Lomotey, 271–283. Albany: State University of New York Press.

Torche, Florencia. 2011. "Is a College Degree Still the Great Equalizer? Intergenerational Mobility across Levels of Schooling in the United States." *American Journal of Sociology* 117 (3): 763–807.

Tyson, Will, Reginald Lee, Kathryn M. Borman, and Mary Ann Hanson. 2007. "Science, Technology, Engineering, and Mathematics (STEM) Pathways: High School Science and Math Coursework and Postsecondary Degree Attainment." *Journal of Education for Students Placed at Risk* 12 (3): 243–270.

van Langen, Annemarie, and Hetty Dekkers. 2005. "Cross-National Differences in Participating in Tertiary Science, Technology, Engineering and Mathematics Education." *Comparative Education* 41 (3): 329–350.

Watkins, Jessica, and Eric Mazur. 2013. "Retaining Students in Science, Technology, Engineering, and Mathematics (STEM) Majors." *Journal of College Science Teaching* 42 (5): 36–41.

Xu, Yonghong Jade. 2008. "Gender Disparity in STEM Disciplines: A Study of Faculty Attrition and Turnover Intentions." *Research in Higher Education* 49 (7): 607–624.

Zhou, Xueguang. 2005. "The Institutional Logic of Occupational Prestige Ranking: Reconceptualization and Reanalyses." *American Journal of Sociology* 111 (1): 90–140.

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CHAPTER 4

Exploring the Relationship Between STEM Research and World Higher Education Rankings: The Case of Taiwan

Jason Cheng-Cheng Yang

Introduction

Higher education institutions in East Asia have made efforts to enhance the quality of students, faculty members, research, and global impacts in order to achieve the status of "World-Class University" (Deem et al. 2008). Shin and Harman (2009) identified massification, privatization, accountability and governance, internationalization, and ranking/world-class university status as the five main topic areas for analyzing higher education in Asia. These five main topics influence and interrelate to each other. Thus, accountability is emphasized and university governance has also changed to cope with mass higher education. The trend among leading universities in Taiwan of pursuing internationalization and world-class status is a response to accountability and world higher education rankings (Lo 2009).

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*,
International and Development Education,
https://doi.org/10.1007/978-3-319-98666-1_4

Of the five factors highlighted by Shin and Harman (2009), world university rankings have important impacts on higher education. Hazelkorn (2009) predicted several impacts of ranking on higher education, including, first, the significant growth of English-taught specialist/professional master's degree programs to attract international students. Second, universities throughout the world might be expected to try to harmonize programs with models in the USA or Europe—namely to Westernize the outlook and curriculums of international programs. Third, research outcomes would become even more important. Fourth, and finally, universities throughout the world would allocate their resources to the fields or disciplines that would be more productive in the world's higher education ranking indicators (i.e., science, technology, engineering, and mathematics [STEM]).

Although world university rankings have impacted different aspects of higher education institutions, they are not the only influencers of higher education. Another important trend is the focus on STEM and its impact on higher education. In recent years, OECD countries have promoted science and technology policies because of their beneficial effect on innovation and economic development. The USA has implemented new science policies to ensure that higher education institutions produce more STEM degree holders (President's Council of Advisors on Science and Technology 2012). The latest policy published by the Ministry of Science and Technology (MOST) in Taiwan also highlighted technological innovation studies to promote newly innovative industries (Ministry of Science and Technology in Taiwan 2017a). Taiwan's latest science policy re-emphasized the importance of scientific studies on the local social and economic development (Ministry of Science and Technology in Taiwan 2017a). This approach tries to strike a balance between the global impact of science and technology and their local contributions.

Indeed, this study chose Taiwan as a case to explore the relationship between STEM research and world higher education rankings for several reasons. First, Asia is a region highly influenced by higher education rankings. Deem et al. (2008, p. 88) asserted that, "with strong intentions to enhance their global competitiveness, governments and universities in Asia have taken university-ranking exercises very seriously." Second, Taiwan is famous for its high-technology industry. The so-called Taiwan Economic Miracle and Asian Four Tigers phenomenon highlight the role that Taiwan's high technology and human capital have played in its economic development (Lee et al. 1994). Third, Taiwan has a long tradition of strong investment in education (Woo 1991) and the technology industry (Hsu and Chiang 2001), as well as a history of linking education, industry, and human resources.

Another important reason for choosing to study Taiwan's reactions to world higher education rankings, as opposed to other Asian countries, is that Taiwan is a society now developing its reflections on globalization and cultural colonization. As Law (2004) asserted, the local nature of education policy in the global age can be seen in Taiwan's recent educational reforms, which challenge certain assumptions of globalization's impact on educational practices. Taiwan's heritage has been influenced by Chinese culture and language, and its current culture values human rights and democracy (Wong 2003). In terms of higher educational practices in Taiwan, in response to the globalization of academic works, actions that professors in Taiwan have called "anti-SSCI (Social Sciences Citation Index)" and "anti-world ranking" are taken seriously (Chou 2014).

STEM fields play an important role in research and development for both nations and higher education institutions. It is hypothesized that STEM can help graduates acquire higher employment opportunities while at the same time helping universities achieve higher rank. However, it also causes an imbalanced development between the humanities and social sciences on the one hand, and STEM fields on the other, at both the university level and nationwide. It is important to explore this issue further. As Perng (2018) pointed out, Taiwan used to have a long history of valuing the contribution of humanity and social sciences to the social development, but due to the concept of learning from the West and to rebuild national competitiveness by investing technology, gradually the Taiwanese society highly favors talents and knowledge of STEM fields and neglects the importance of humanities (重理工輕人文). At the university level, faculty's promotion to become an associate or full professor in Taiwan will be evaluated by content quality and also accumulated numbers of their international journal articles. Institution's research awards are also evaluated by the standards of SCI and SSCI articles and tier ranks of the journals that professors published (Chou 2014). But academic outcomes of arts and humanity are sometimes applying more to local knowledge and indigenous contexts. Sometimes the field of arts considers actual performance instead of producing journal papers. At the national level, most of the research-type universities nominated by the Taiwan government are the universities with a lot of departments of STEM subjects (Perng 2018).

This research project collected data from the statistical databases of the main governmental websites of Taiwan, such as the MOST. In terms of statistical data regarding STEM and non-STEM academic publication trends in Taiwan, data was collected from the SCImago Journal & Country Rank website, which is a publicly available database that provides multination information on academic publication trends and is developed from the Scopus database (SCImago 2017a).

University Types and Students in Taiwan: Statistical Trends of the Technology Field and Other Fields

In this section, statistical data collected from the Ministry of Education in Taiwan were analyzed to depict the trends among different types of universities in Taiwan. Figure 4.1 shows the total number of general and technological universities in Taiwan. Currently, 158 comprehensive universities exist in Taiwan: 99 general universities and 59 technological universities (as of 2016). As the figure indicates, the gap between the two types of universities has

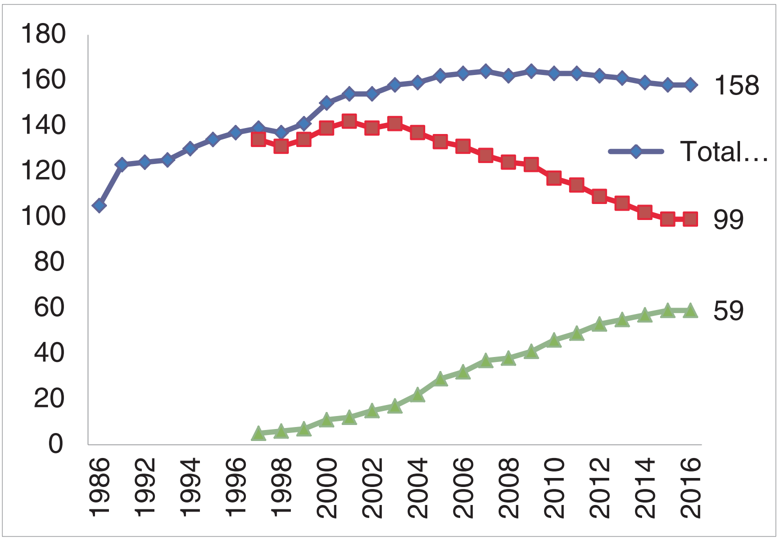

Fig. 4.1 Change of numbers of general and technological universities in Taiwan. Blue color data line: Number of All Universities in Taiwan. Red color data line: Number of General Universities in Taiwan. Green color data line: Number of Technological Universities in Taiwan (*Source* Ministry of Education in Taiwan 2017a)

gradually decreased over time due to Taiwan's "Two-Educational Highway Policy" (兩條國道教育政策), announced by the government in 1996. The concept behind this policy was to offer higher educational opportunities to vocational high school graduates, who used to have few such options. Since then, more technological universities in Taiwan have been established or upgraded from vocational junior colleges (Lin and Chan 2004). The "Two-Educational Highway Policy" and the increasing number of technological universities can also be understood as examples of Taiwan's emphasis on the fields of science, technology, and engineering. The role of technological universities in the Taiwanese education system is to emphasize practice and to apply latest techniques and technology in the industry. However, due to the reasons that most of their faculty is trained in the academic universities, faculty promotion considered more academic publications, and the impacts of standards of international higher education rankings. The role of technological universities becomes more and more similar with other academic universities in Taiwan. To cope with this trend, Ministry of Education in Taiwan implemented the "Second Phase Vocational Education Re-Structure Project 第二期技職再造計畫" to redirect the technological universities to balance research and practice of STEM fields (Rau 2015).

Figures 4.2, 4.3, and 4.4 are percentages of different majors among bachelor's-level students, master's-level students, and doctoral-level

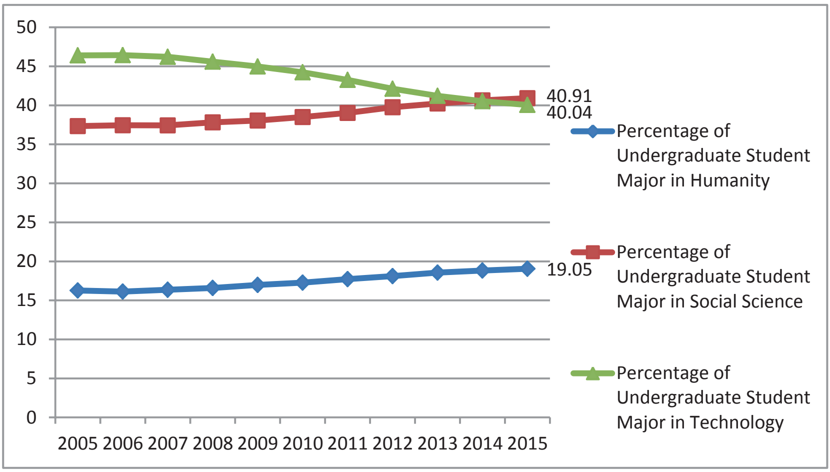

Fig. 4.2 Percentage of bachelor's-level students' majors in Taiwan, 2005–2015 (*Source* Ministry of Education in Taiwan 2017b)

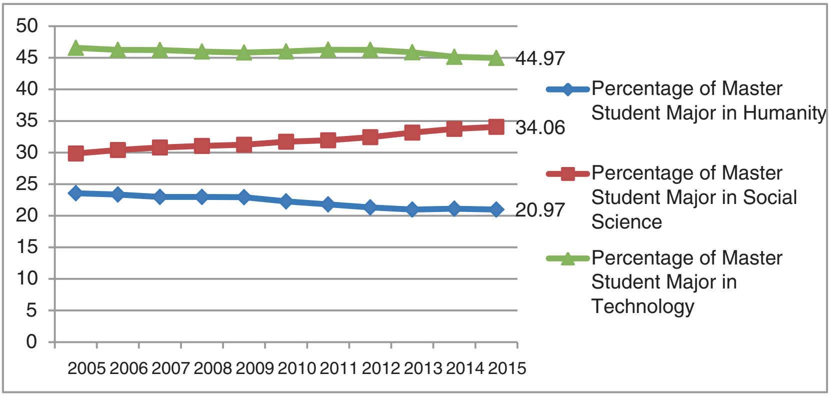

Fig. 4.3 Percentage of master's-level students' majors in Taiwan, 2005–2015 (*Source* Ministry of Education in Taiwan 2017c)

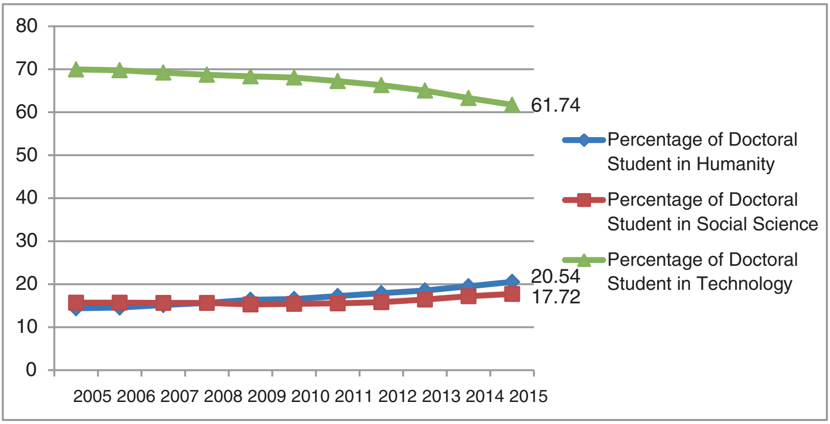

Fig. 4.4 Percentage of doctoral-level students' majors in Taiwan, 2005–2015 (*Source* Ministry of Education in Taiwan 2017d)

students, respectively, enrolled in Taiwanese universities (including all general universities and technological universities). Figure 4.2 indicates that, in terms of absolute numbers, significantly smaller percentages of students major in humanities, while almost 40% major in social sciences and 47% major in technology. Yet overall, humanities and social sciences undergraduate majors are on an upward trajectory while technology majors are decreasing. The differences at the master's level show similar trends, although significantly more graduate students are still majoring in technology than in humanities or social sciences. Finally, Fig. 4.4 shows that although the number of doctoral students majoring in technology is decreasing in Taiwan, they still account for 61.74% of all doctoral students overall. Based on these figures, the higher the educational level is the more students major in technology; this trend reflects both students' individual choices and a governmental emphasis on promoting technology majors in higher education.

Figure 4.5 depicts the data collected from Taiwan's Ministry of Education regarding the percentages of all professors who worked at all universities in Taiwan and their research expertise from 2005 to 2015. These data show a relatively higher percentage of professors whose expertise is in science and technology disciplines, as well as a trend toward more professors with expertise in social science-related disciplines. Thus, although there is a significant divide among

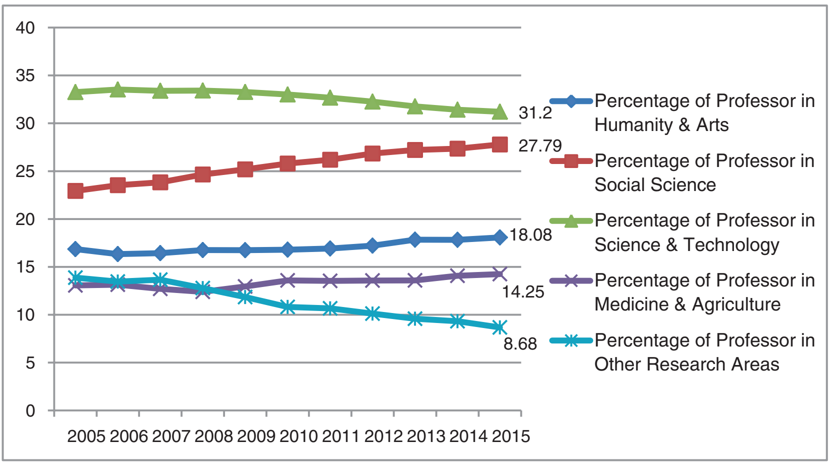

Fig. 4.5 Percentage of professors in research expertise in Taiwan, 2005–2015 (*Source* Ministry of Education in Taiwan 2017e)

humanities, social sciences, and technology in terms of postgraduate students' major selection, when looking at professors' expertise distribution throughout the whole higher education system in Taiwan, an adjustment of discipline differences and the equalization of research areas have been occurring.

Top Four Universities' Rankings and Annual Research Funds of Research Divisions in MOST of Taiwan

Table 4.1 summarizes information from the top four universities in Taiwan—namely the number of STEM-field and non-STEM-field colleges and the academic expertise of the universities' presidents, which is consistently related to STEM fields.

Figure 4.6 shows the average amount of annual research funds for the four divisions of the MOST in Taiwan. MOST is the government's major organization promoting science and technology, research and development, academic research, and science industry parks (Ministry of Science and Technology in Taiwan 2017b). This figure shows huge gaps in the annual average funds for STEM, humanities, and social sciences for developing academic research; this difference is obvious and long term.

Table 4.1 Number of STEM-field colleges, president's expertise, and world ranking of top four universities in Taiwan

	Number of STEM-field colleges	*Number of non-STEM-field colleges*	*President's academic expertise*	*QS world ranking (2016)*	*The world ranking (2016)*
National Taiwan University	7	4	Medicine	68	81–90th
National Tsing-Hua University	5	3	Mechanical Engineering	151	251–300th
National Chiao-Tung University	6	3	Electronic Engineering	174	301–350th
National Cheng-Kung University	5	4	Public Health	241	401–500th

Source Author collected from main websites of four universities

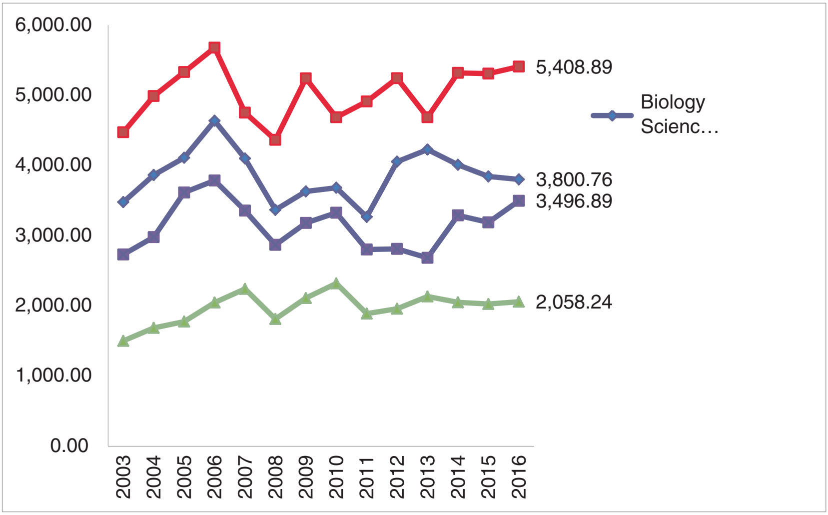

Fig. 4.6 Average annual research funds of different research divisions in MOST of Taiwan. Red color data line: Engineering Division. Light Blue color data line: Biology Science Division. Dark Blue color data line: Nature Science Division. Green color data line: Humanity and Social Science Division (*Source* Ministry of Science and Technology in Taiwan 2017b)

Comparison of Ranking Indicators of Three World Higher Education Rankings

There are three major world higher education rankings. QS started ranking global higher education in 2004. Times Higher Education was originally the same organization as QS, but began working independently in 2010. The Academic Ranking of World Universities (ARWU), established by Shanghai Chiao-Tung University, started to rank world universities in 2003. The three world higher education rankings share both similarities and differences. First, all three rankings give significant weight to university faculty members' and researchers' research publications. Second, QS and Times Higher Education view the internationalization of higher education institutions as an important indicator. For example, QS gives 5% to "proportion of international faculty" and 5% to "proportion of international students" while Times Higher Education gives 7.5% to "international outlook." ARWU gives very high weights to university research outcomes: 20% to "highly cited researchers," 20% to

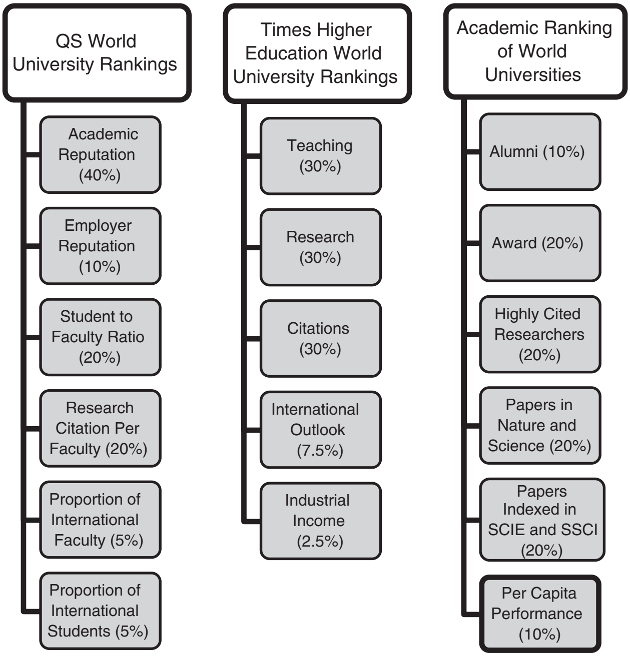

Fig. 4.7 Indicators and weights of three world higher education rankings (*Source* Academic Ranking of World Universities 2017, QS World University Rankings 2017, and Times Higher Education World University Rankings 2017)

"papers in nature and science," and 20% to "papers indexed in SCIE and SSCI." Finally, all three rankings provide information on world universities' subject-specific rankings, which could strengthen discipline differences (Fig. 4.7).

Comparison of Research Publication Outcomes of STEM and Non-STEM Fields in Taiwan, China, Japan, and the USA

For this paper, I collected data on research publication outcomes from the SCImago Journal & Country Rank website. Figure 4.8 presents the total number of citable documents in Taiwan, China, Japan, and the

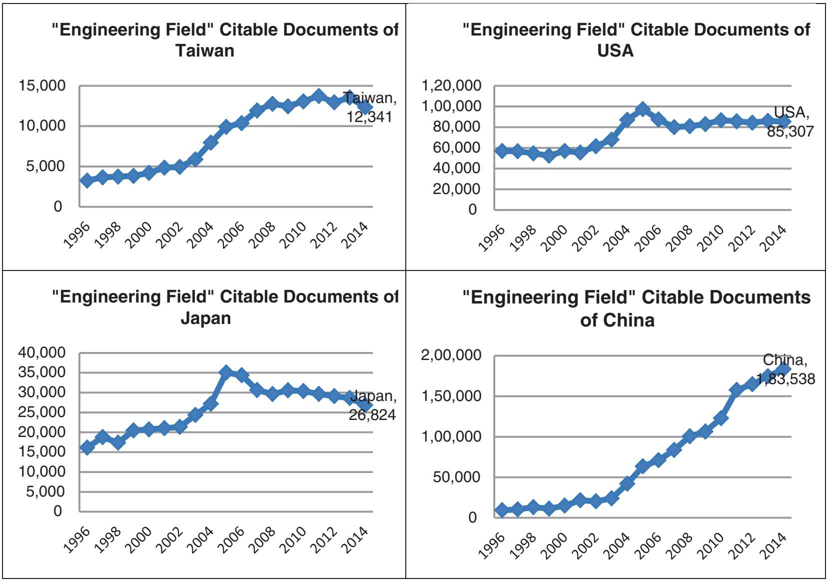

Fig. 4.8 Engineering field research publications (citable documents) in Taiwan, China, Japan, and the USA (*Source* SCImago 2017b)

USA in the field of engineering. Comparing these four countries, China has the highest total number; its growth rate has also been fastest since the 2000s. The fact that China's scientific publications have been growing so fast in the field of engineering could possibly relate to its 211 Project (High-Level Universities and Key Disciplinary Fields) and 985 Project (World Class Universities)—governmental policies which aim to build the research capacity of Chinese universities (Zhang et al. 2013). Japan and the USA experienced a surge in engineering publications between 2004 and 2006 before returning to the normal curve. Taiwan's engineering publications have continued to grow since the 2000s, when the government started the national project "Building World Class Universities" (Song and Tai 2007). Because of the influence of national policy, all four countries have shown significant growth in engineering publications since the 2000s, especially in 2003 and 2004. This trend could relate to the initiation of world higher education rankings.

Figure 4.9 presents the total number of citable documents in Taiwan, China, Japan, and the USA in the arts and humanities. Although arts and

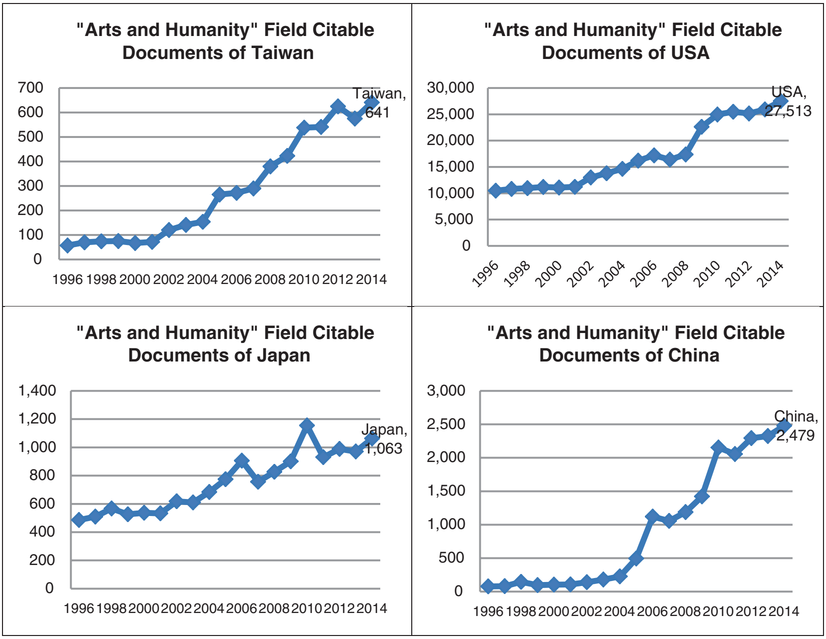

Fig. 4.9 Arts and humanity field research publications (citable documents) in Taiwan, China, Japan, and the USA (*Source* SCImago 2017b)

humanities cannot compare with engineering in terms of quantity, the trends in these different fields are similar. The arts and humanities fields may also thus be influenced by world higher education rankings and national science policies in these four countries.

Figure 4.10 offers more evidence regarding the trend in the number of citable documents in Taiwan in engineering, mathematics, arts and humanities, and social sciences. Although the total number of scientific articles cannot be compared in these four disciplines, the trends in all four are similar. The publication trends in these four fields correlate to national science policies and the emergence of world higher education rankings in Taiwan.

Table 4.2 represents the top 10 journals in the engineering field, according to their rank in the SJR system. The SCImago Journal & Country Rank website recently developed its SJR2 indicator to help rank journals in one academic field that represents their journal citation

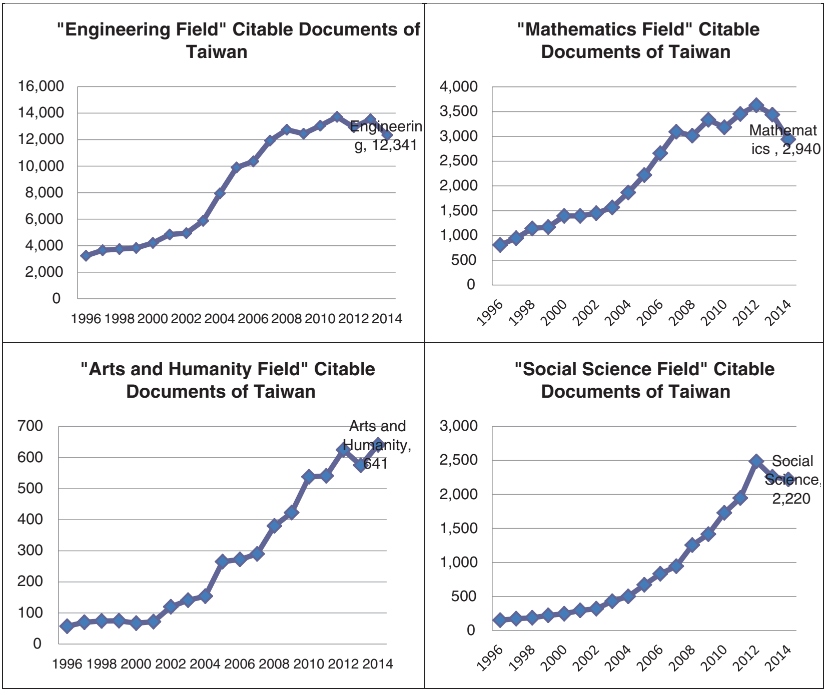

Fig. 4.10 Engineering field, mathematics field, arts and humanity field, and social science field of research publications (citable documents) in Taiwan (*Source* SCImago 2017b)

network (Guerrero-Bote and Moya-Anegon 2012). The SJR2 indicator uses weighed citation numbers to show a journal's impact power. When a journal ranks higher in the SJR2 system, it has a higher influence on citation numbers and citation behaviors in the academic field. According to Tables 4.2 and 4.3 (which shows the top 10 journals in education, as ranked in the SJR system), relatively more interdisciplinary journals exist in education than engineering. For example, *Journal of Research in Science Teaching*, *Internet and Higher Education*, *Journal of the Learning Sciences*, and *Computers and Education* became top education journals in 2015. Only one journal, *Journal of Engineering Education*, ranked higher in engineering. When world higher education rankings influence

Table 4.2 Top 10 engineering field journals in SJR2

Rank in SJR	*2005*	*2010*	*2015*
1.	*Nature Materials*	*Nature Materials*	*Nature Materials*
2.	*Nano Letters*	*Nature Nanotechnology*	*Nature Nanotechnology*
3.	*Advanced Materials*	*Materials Science and Engineering: R: Reports*	*Nature Biotechnology*
4.	*IEEE/ACM Transactions on Networking*	*Nano Letters*	*Advanced Materials*
5.	*Nature Biotechnology*	*Nature Biotechnology*	*Nano Letters*
6.	*IEEE Journal on Selected Areas in Communications*	*Advanced Materials*	*Materials Science and Engineering: R: Reports*
7.	*IEEE Transactions on Power Electronics*	*Journal of Engineering Education*	*ACS Nano*
8.	*IEEE Wireless Communications*	*Nano Today*	*Materials Today*
9.	*IEEE Communications Magazine*	*Materials Today*	*Nano Today*
10.	*IEEE Transactions on Communications*	*ACS Nano*	*Journal of Engineering Education*

Source SCImago (2017c)

Table 4.3 Top 10 education field journals in SJR2

Rank in SJR	*2005*	*2010*	*2015*
1.	*Review of Educational Research*	*Journal of Engineering Education*	*Journal of Engineering Education*
2.	*Journal of the Learning Sciences*	*Journal of Research in Science Teaching*	*American Educational Research Journal*
3.	*Child Development*	*Review of Educational Research*	*Journal of Research in Science Teaching*
4.	*Educational Evaluation and Policy Analysis*	*Science Education*	*American Journal of Education*
5.	*Journal of Educational Psychology*	*Child Development*	*Internet and Higher Education*
6.	*Journal of Research in Science Teaching*	*Educational Evaluation and Policy Analysis*	*Review of Educational Research*
7.	*Harvard Educational Review*	*Journal of Educational Psychology*	*Journal of the Learning Sciences*
8.	*Science Education*	*Scientific Studies of Reading*	*Journal of Teacher Education*
9.	*Language Learning*	*Developmental Review*	*Computers and Education*
10.	*Journal of Special Education*	*Journal of Second Language Writing*	*Child Development*

Source SCImago (2017c)

the academic world to produce more research articles, they gradually influence social science disciplines, such as education. When the government and universities require researchers to produce more research articles, cooperation between STEM and non-STEM researchers can be predicted.

Programs and Strategies for Linking STEM with Other Disciplines in Higher Education in Taiwan

Through the analyses above, it can be observed that world higher education rankings reinforce the importance of publications and national science policies continue to favor STEM fields when over-emphasizing publication numbers. However, it is also important to link STEM with other disciplines in higher education because future talents in the globalizing world should possess multiple abilities. In the knowledge-based economy era, high-level talents who can integrate interdisciplinary knowledge are indispensable (Wang et al. 2011).

In Taiwan, some recent programs and strategies have been designed to promote interdisciplinary teaching and learning. In 2005, the Legislative Yuan of Taiwan revised the University Law to allow universities to establish stand-alone, college-based degree programs within universities, in which students can choose courses from different departments. Thus, starting in 2007, more interdisciplinary programs have been established at major Taiwanese universities (Wang et al. 2011).

There is another important trend in Taiwan's higher education: internationalization. Taiwanese universities are now making efforts to recruit international faculty members and students (Chin and Ching 2009). To respond to this trend and resolve internal problems related to the mixture of Chinese-language courses and English-language courses, many universities in Taiwan have started to establish full-English instruction degree programs and international colleges. Most courses at Taiwanese universities are taught in traditional Chinese, but the growing number of international students on campus means the number of full-English-language courses should be expanded. An efficient way to achieve this is to establish full-English programs within specific colleges of universities. The courses comprising these programs are generally offered by professors from different departments university-wide. Examples of such English-taught programs in the field of education are the Master's Program in Educational Leadership and Management Development (ELMD) at National Chung Cheng University (established in 2012); the Global Master's Program for the Teaching Profession at National Chiayi University (established in 2014); and the International Master's Program of Learning and Instruction at National Taipei University of Education (established in 2016). Through such programs, Taiwanese universities will gradually be able to incorporate interdisciplinary or multidisciplinary features in teaching and learning. Faculty members involved are from different departments throughout the university.

Another new concept in the organizational structure of higher education emerged with the establishment of full-English-language international programs—namely the international college. International colleges in Taiwan developed when various universities decided to place all international programs into dedicated colleges in order to manage their English-taught courses, foreign faculty members, and international students (some universities also recruited domestic students who wanted to receive instruction in English). Since, with this type of structure, international programs spanning different disciplines are all managed within the same international college, students can not only take courses from a variety of disciplines, they can also gain a more international perspective. One example of such an international college is Tunghai University in Taichung City, Taiwan. This university established its international college in 2014. As stated on its website, "THU's International College is the first English-Immersion undergraduate program in Taiwan" and "in striving to achieve this vision, the International College is committed to providing an English immersion environment, interdisciplinary curriculum, experiential learning, and multi-cultural experiences" (Tunghai University International College 2017). These statements highlight the benefits of establishing an international college within a Taiwanese university: interdisciplinary learning, multicultural experiences, and an English-immersion environment. Another benefit is the greater efficiency of managing all international courses, faculty members, and students in the same college. At the same time, the disadvantage of the international college is that it is isolated from other local programs and loses the benefits of integrating domestic and international faculty members and students.

Conclusion

Higher education in Asia has been influenced by the phenomena of massification, privatization, accountability, and internationalization, as well as the pursuit of world-class status in international rankings (Shin and Harman 2009). Taiwan is no exception. National policies in Taiwan encourage top universities to pursue world-class status and greater internationalization. But ranking indicators and science policies continued giving advantages to STEM fields. The three main rankings have based their ranking indicators on two factors: publications and citations, and internationalization. In the case of Taiwan, rankings not only correlate with the trend in publications in the STEM fields, but they also relate to the trends of publications in the humanities and social sciences.

The forming of a knowledge-based economy urged university students possess interdisciplinary knowledge and abilities to cope with the changing labor market. Based on the analysis, top journals in the field of education have gradually developed in interdisciplinary or multidisciplinary directions, and more interdisciplinary journals are needed in the STEM field.

The newest strategy that Taiwanese universities have used to internationalize their teaching and learning environment is the establishment of English-language international programs, up to and including entire English-environment international colleges. The advantages of having an international college at a local university include interdisciplinary teaching and learning, and multicultural experiences. International colleges can also engage domestic students in multicultural and interdisciplinary experiences. Nevertheless, further empirical studies on the internal practices and the external effects of establishing international colleges are necessary.

References

Academic Ranking of World Universities. 2017. "ARWU 2016 Methodology." Accessed April 25, 2017. http://www.shanghairanking.com/ARWU-Methodology-2016.html.

Chin, Joseph Meng-Chun, and Gregory S. Ching. 2009. "Trends and Indicators of Taiwan's Higher Education Internationalization." *The Asia-Pacific Education Researcher* 18 (2): 185–203.

Chou, Chuing Prudence, ed. 2014. *The SSCI Syndrome in Higher Education: A Local or Global Phenomenon*. Rotterdam: Sense Publishers.

Deem, Rosemary, Ka Ho Mok, and Lisa Lucas. 2008. "Transforming Higher Education in Whose Image? Exploring the Concept of the 'World-Class' University in Europe and Asia." *Higher Education Policy* 21 (1): 83–97.

Guerrero-Bote, Vicente P., and Felix Moya-Anegon. 2012. "A Further Step Forward in Measuring Journals' Scientific Prestige: The SJR2 Indicator." *Journal of Informetrics* 6: 674–688.

Hazelkorn, Ellen. 2009. "Rankings and the Battle for World-Class Excellence: Institutional Strategies and Policy Choices." *Higher Education Management and Policy* 21 (1): 1–22.

Hsu, Chiung-Wen, and Hsueh-Chiao Chiang. 2001. "The Government Strategy for the Upgrading of Industrial Technology in Taiwan." *Technovation* 21 (2): 123–132.

Law, Wing-Wah. 2004. "Translating Globalization and Democratization into Local Policy: Educational Reform in Hong Kong and Taiwan." *International Review of Education* 50 (5): 497–524.

Lee, Maw-Lin, Ben-Chieh Liu, and Ping Wang. 1994. "Growth and Equity with Endogenous Human Capital: Taiwan's Economic Miracle Revisited." *Southern Economic Journal* 61 (2): 435–444.

Lin, Yung-Feng, and Sheng-Ju Chan. 2004. "On the Differentiation Framework of the Post-Compulsory Education in Taiwan: A Perspective Based on the Reflection on the Two-Educational Highway Policy." *Educational Research & Information* 12 (6): 59–84.

Lo, William Yat Wai. 2009. "Reflections on Internationalisation of Higher Education in Taiwan: Perspectives and Prospects." *Higher Education* 58 (6): 733–745.

Ministry of Education in Taiwan 臺灣教育部. 2017a. "dà zhuān xiào yuàn xiào shù tǒng jì 大專校院校數統計" [Number of Total Higher Education Institutions]. Accessed July 20, 2017. http://stats.moe.gov.tw/files/important/OVERVIEW_U03.pdf.

Ministry of Education in Taiwan 臺灣教育部. 2017b. "dà xué shēng jiù dú lèi kē zhī bǐ lǜ 大學生就讀類科之比率" [Percentages of Major Disciplines of Undergraduate Students in Taiwan]. Accessed July 20, 2017. http://stats.moe.gov.tw/files/important/OVERVIEW_U04.pdf.

Ministry of Education in Taiwan 臺灣教育部. 2017c. "shuò shì shēng jiù dú lèi kē zhī bǐ lǜ 碩士生就讀類科之比率" [Percentages of Major Disciplines of Master-Level Students in Taiwan]. Accessed July 20, 2017. http://stats.moe.gov.tw/files/important/OVERVIEW_U05.pdf.

Ministry of Education in Taiwan 臺灣教育部. 2017d. "bó shì shēng jiù dú lèi kē zhī bǐ lǜ 博士生就讀類科之比率" [Percentages of Major Disciplines of Doctoral-Level Students in Taiwan]. Accessed July 20, 2017. http://stats.moe.gov.tw/files/important/OVERVIEW_U06.pdf.

Ministry of Education in Taiwan 臺灣教育部. 2017e. "dà zhuān xiào yuàn shī zī zhuān cháng fēn pèi jié gòu 大專校院師資專長分配結構" [Expertise Distribution Structure of Professors at Higher Education Institutions in Taiwan]. Accessed July 20, 2017. http://stats.moe.gov.tw/files/important/OVERVIEW_U14.pdf.

Ministry of Science and Technology in Taiwan 臺灣科技部. 2017a. "kē jì bù èr líng yī qī dào èr líng èr líng nián zhōng chéng zhèng cè jì huà 科技部 2017 到2020 年中程政策計畫" [Mid-Term Policy Plan of Ministry of Science and Technology (2017–2020)]. Accessed July 20, 2017. https://www.most.gov.tw/most/attachments/1925ec5e-a6b8-4013-988e-17bb45b0dd24.

Ministry of Science and Technology in Taiwan 臺灣科技部. 2017b. "zhuān tí yán jiù jì huà shēn qǐng hé dìng jīng fèi qū shì tú 專題研究計畫申請核定經費趨勢圖" [Figures of Trends of Research Project Application and Awarded Fund]. Accessed July 20, 2017. http://statistics.most.gov.tw/was2/.

Perng, Tsong-Pin. 2007. "tái wān rén wén zhèng cè de wǒ jiàn wǒ sī 台灣人文政策的我見我思" [My View and Thinking on Taiwanese Humanity Policies]. Accessed May 18, 2018. http://www.mse.nthu.edu.tw/~tpperng/Articles_eng.html.

President's Council of Advisors on Science and Technology. 2012. "Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics." Accessed April 26, 2017. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pcast-executive-report-final_2-13-12.pdf.

QS World University Rankings. 2017. "Methodology." Accessed April 25, 2017. https://www.topuniversities.com/qs-world-university-rankings/methodology.

Rau, Bang-An. 2015. "jì shù jí zhí yè jiāo yù fǎ gōng bù shí shī hòu jì zhí xiào yuàn zhī yīn yīng 技術及職業教育法公布實施後技職校院之因應" [Reactions of Vocational Schools After the Publication of Technical and Vocational Education Law]. Accessed May 18, 2018. regist.cyut.edu.tw/Personnel/GActApp/Download/3.

SCImago. 2017a. "About Us." Accessed April 20, 2017. http://www.scimagojr.com/aboutus.php.

SCImago. 2017b. "Country Rankings." Accessed April 20, 2017. http://www.scimagojr.com/countryrank.php.

SCImago. 2017c. "Journal Rankings." Accessed April 20, 2017. http://www.scimagojr.com/journalrank.php.

Shin, Jung Cheol, and Grant Harman. 2009. "New Challenges for Higher Education: Global and Asia-Pacific Perspectives." *Asia Pacific Education Review* 10 (1): 1–13.

Song, Mei-Mei, and Hsiou-Hsia Tai. 2007. "Taiwan's Responses to Globalisation: Internationalisation and Questing for World Class Universities." *Asia Pacific Journal of Education* 27 (3): 323–340.

Times Higher Education World University Rankings. 2017. "World University Rankings 2016–2017 Methodology." Accessed April 25, 2017. https://www.timeshighereducation.com/world-university-rankings/methodology-world-university-rankings-2016-2017.

Tunghai University International College. 2017. "About the College." Accessed April 23, 2017. http://ic.thu.edu.tw/web/about/page.php?scid=14&sid=16.

Wang, Hsiou-Huai, Ai-Chu Ding, and Ai-Lan Su. 2011. "Crossing the Border of Disciplinary Knowledge: An Analysis of the Choice of Major at the Upper Level of College in Research-Oriented Comprehensive Universities, with the Use of One Case Study Based on Student Needs in Taiwan." *Journal of Research in Education Sciences* 56 (3): 1–30.

Wong, Joseph. 2003 "Deepening Democracy in Taiwan." *Pacific Affairs* 76 (2): 235–256.

Woo, Jennie Hay. 1991. "Education and Economic Growth in Taiwan: A Case of Successful Planning." *World Development* 19 (8): 1029–1044.

Zhang, Han, Donald Patton, and Martin Kenney. 2013. "Building Global-Class Universities: Assessing the Impact of the 985 Project." *Research Policy* 42 (3): 765–775.

CHAPTER 5

Finding the Humanities in STEM: Anthropological Reflections from Working at the Intersection

Grant Jun Otsuki

How might a more historically informed understanding of the relations among the science, technology, engineering, and mathematics (STEM) and humanities and social sciences (H&SS) fields shape how we think about the reorganization of institutional priorities and disciplinary structures in the changing global landscape of higher education? In this paper, I write from the perspective of my fields of specialization, anthropology and history of science and technology, to reflect on how we might think of the relationship between STEM and H&SS. I want to highlight how the boundary between these two broad areas is often productively crossed, particularly at points we would expect them to be most different: where new knowledge is being created. I will discuss cases in which people have worked across this boundary in ways that defy easy categorization as STEM or H&SS. These interactions, I suggest, are as

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*,
International and Development Education,
https://doi.org/10.1007/978-3-319-98666-1_5

important to the work of scientists as they are under-recognized. I argue that one challenge facing universities today is to articulate the value of these under-recognized interactions, and foster an environment in which they may be developed.

An Ethnographic Opening

Early in 2016, just before the beginning of the new school semester, the faculty who had recently joined the university in Japan to which I then belonged were gathered in a large campus meeting hall for the new instructor orientation. As I entered, I was handed a paper bag full of materials about the institution, its organizational structure, and the agenda for the afternoon. Finding a seat near the middle of the room, I turned an eye to the people around me. There was a wide variation in age, but the average may have leaned toward the late 30s and early 40s. As I browsed the papers that had been given to me, I found a great deal of information that I wished I had known at the actual time of my appointment, more than six months earlier. But as with any large organization, the rhythm of those administering the university as a whole rarely synchronizes with that of the individual professor.

The orientation session began at 1:30 p.m. Remarks from the university's president set things off on a joltingly pessimistic note. Broad demographic changes would force student numbers down with no chance of significant recovery in the near future. The quality of the students admitted was similarly expected to decline, as competition among similarly ranked institutions increased. Direct funding from the national government would never again reach the levels of the past; the size of the faculty would need to be cut by a substantial proportion. It was up to us to fight for external grants, forge international collaborations, and, of course, publish. I felt naïve to have expected some words from the leadership about the mission of the institution, its traditions and record, and an inspiring vision for the future. Instead, the president opened a door on the other side of which was a declining ecosystem in which survival of any one person would depend on their individual fitness. Do more with less. The most successful among us would be the ones who would help the university prosper.

One of the primary drivers of such demands in Japanese universities is the increasing emphasis placed by university administrators and government policymakers on global and national university rankings (see Stevenson's Chapter 2 of this volume). Japanese universities are far from unfamiliar with ranking pressures—prospective students, aided by their high schools and *juku* (preparatory cram schools), regularly make use of various metrics to make choices about which universities to attempt to enter. However, the broadening of rankings from the national to international scope has changed the calculus that drives the educational and research priorities of Japanese universities (see Yamada's Chapter 1 of this volume), often tilting the balance in favor of the STEM fields.

This shift was manifested in the introductory address given by my university's president at the orientation session. Throughout his address, I was struck not by the lack of mention of the humanities and social sciences, but the ways in which they were mentioned. They seemed always to come at the end of a list after the final comma—"as well as the social sciences and humanities"—in the way that one might mention "other minorities" in the interest of ethnic inclusivity. My intention is not to suggest that we in the humanities and social sciences are an oppressed minority. At that institution, H&SS students are the largest group, and are hardly without a voice. Moreover, the institutional pressures that my colleagues and I in H&SS face are not unknown by our colleagues in STEM. But what struck me about this framing of our disciplines is the existence of sharp boundaries between H&SS and STEM that such statements imply.

The division between ethnic groups often involves the assumption of difference, even at levels where difference may not be practically meaningful. Further, it tends to be treated as a consequence of differences in essence rather than the outcome of variously converging and diverging discourses and practices. Similarly, the division between H&SS and STEM is often a misrecognition of what makes these disciplinary clusters different. The boundary seems to exist first because of essential differences in the nature and forms of inquiry and knowledge that the disciplines produce. These are extended into organizational structures, student and faculty identities, and the public consciousness. In fact, there are few reasons to think that the boundary is as rigid or as total as we tend to assume. What if the STEM and non-STEM fields share much more than we usually think? How might such a recognition change the calculus that universities and policymakers use to set their institutional priorities?

Looking Back to Cybernetics

My thoughts about these questions have been informed by my ongoing research into the history of cybernetics. The word "cybernetics" may sound outdated or a part of science fiction, but cybernetics is a science in which many of the fundamental ideas of modern information and communication theory were developed. Self-regulating machines and information processing systems, robots, and computers were the stuff of cybernetics, and cybernetic theories such as signal and noise, or disorder and purpose, emerged to make them and make sense of them.

The heyday of cybernetics as a field was in the 1960s, not only in the United States but around the world. The pioneering figure of cybernetics, MIT mathematician Norbert Wiener, was something of a celebrity. He was a sought-after public speaker, his books were reviewed in the *New York Times*, and his face and words appeared in *Life* magazine. This was a period in which cybernetics was being trumpeted in popular and academic circles as a new science for understanding the computer as an artificial brain, and the human brain as a thinking machine. It was also a period in which hopes and fears about a new "industrial revolution" driven by technologies of computation and automation took root in the popular imagination. Computers were not yet called computers but "new brains" or "electronic brains." It was recognized by some that it would only be a matter of time before new technologies would replace human workers in a range of thinking occupations, concerns that have by no means been assuaged today. Since then, the term "cybernetics" itself has fallen into disuse or misuse, but the basic principles presented by cybernetic thinkers have continued to serve as the groundwork for our current information age (Kline 2015).

The standard story about cybernetics is that it was a science forged in the crucible of World War II (Galison 1994). It was Wiener, and the other men enlisted to create systems to automatically track and shoot down enemy aircraft, who developed cybernetics as a theory of self-regulating, goal-seeking, electro-mechanical systems. If, as Ronald Kline (2015) has argued, cybernetics then went on to turn our age into the "information age," then according to this story, it is because of its success in recasting the rest of the social and natural world into versions of the mechanized battlefields of World War II. This image is a "globalized, even metaphysical, extension of the epochal struggle between the implacable enemy from the sky and the Allies' calculating [prediction systems] that did battle from the ground." (Galison 1994, p. 266).

Dominant images of cybernetics reproduce two features of the prevailing view of the sciences. First, it takes as a given that scientific research occurs in an area that is more or less isolated and bounded from the rest of society. The state-imposed secrecy that surrounded much wartime research is a concrete actualization of this view, but this is one instance of how cybernetics is represented as a field that developed without inputs beyond the technical and strategic problems of the war. This manifests the assumption that science can be explained without reference to the broader social and historical situation surrounding its emergence. Second, and relatedly, the conventional history of cybernetics describes its social significance in terms of the *impacts* it had following its development as a scientific field. In other words, science is a walled city from which knowledge and ideas diffuse outward to the rest of society, leaving little room for society to shape science, and drawing a sharp line between "science" and "non-science." This was what the philosopher Michael Polanyi (1962) called "the republic of science": "You can kill or mutilate the advance of science, you cannot shape it" (p. 62).

The question of the nature of the boundary between science and society is a version of what is known as the problem of demarcation. What makes science different from non-science or pseudoscience? Is it a difference in subject matter, a difference in method? A difference in the structure of scientific theory as opposed to other forms of knowledge? In my fields of training, this problem is explained as a sociological or cultural one. Sociologist Thomas Gieryn (1983), for instance, proposed that the difference between science and non-science was a result of the work of ideology and what he called "boundary-work." Boundary-work is what scientists do in order to "distinguish their work and its products from non-scientific intellectual activities" (Gieryn 1983, pp. 781–782). In contrast to still-persistent representations of science in philosophy and the social sciences, Gieryn and many others who followed show us that the line between science and non-science is one that had a historical beginning and that is continuously being reproduced through the practices of scientists and non-scientists alike. Afterward, it became the task of social scientists to inquire into how science operated not in opposition or in stark difference to "non-scientific" work, but how often rather ordinary social processes were at the center of the production of scientific knowledge (Bloor 1991). Scientists were driven by personal and professional interests (Mackenzie 1978), or by economic and quasi-economic motivations to accumulate economic and symbolic capital (Latour and Woolgar 1979; Bourdieu 2004). Science is not a city of walls but an orchard; it may have fences, but in order for its trees to bear their fruits it cannot be without the comings and goings of people from the markets and communities, and the light, rain, and pollinating insects of its surrounding ecosystem.

Accordingly, our notions of what science is and what scientists do have diversified considerably. Science, as the postcolonial scholar Itty Abraham (2006) notes, "exists simultaneously as history, as myth, as political slogan, as social category, as technology, as military institution, as modern western knowledge, and as instrument of change" (p. 213). Scientists weave narratives, and they build alliances with people, organisms, and things; they construct institutions and organizations, they train their apprentices, and live within worldviews that are only partly of their own making. Scientists may sometimes see themselves as existing in what anthropologist Sharon Traweek (1988) called "a culture of no culture" (p. 162), having a special relationship with nature that is free of the capricious dynamics of human society. But they are a culture nonetheless, one that has all the features and complexity of any other. Note that none of this comes at the expense of recognizing science as a productive and unique enterprise. It is the nature of its productiveness and its uniqueness that have come under revision.

The upshot is, in contrast to the notion that the STEM and H&SS fields are distinct in essence, these fields are actually built of the same stuff. The languages, organizations, technologies, and values that we mobilize to do our work may differ, but this does not exclude the possibility that STEM and non-STEM people alike might create their respective worlds to address rather similar problems: How do we live and work together? For what purpose are we doing these things? What tools and ideas do we need to use or create? This widens the range of ways in which we can understand what people involved in science are actually doing.

An Interdisciplinary and Intercultural Ecology

If we permit ourselves to take this multilayered view of science as a starting point, then the questions that we can begin to ask about science can change in interesting ways. In my own work, I have used such a multilayered view to investigate how intercultural and interdisciplinary exchanges shaped the early history of cybernetics. This pushes the beginning of cybernetics back before the air battles of World War II to Cambridge, England in 1914. It was here that Norbert Wiener spent a short time after receiving his doctorate. Wiener was barely twenty years old at the time, but he had already completed his graduate studies at Harvard the year before. While Wiener's most famous accomplishments would be in mathematics, physics, and communication theory, early in his career he was a philosopher. He wrote papers about Bertrand Russell and Alfred North Whitehead's *Principia Mathematica* and worked with Russell while in Cambridge. Around this time, he was also under the influence of others like French philosopher Henri Bergson, who would later make a prominent appearance in his cybernetic writing, and Spanish-American philosopher Georges Santayana.

It was in Cambridge where Wiener joined a circle of young philosophers, which included another figure also more famous for his later nonphilosophical accomplishments, the poet T. S. Eliot. They were then both young philosophers who had grown weary and critical of philosophies that sought absolute and complete systems of knowledge. To Eliot, Wiener was "a great wonderful fat toad bloated with wisdom" (Crawford 2015, p. 405), a person who shared his intellectual interests and enthusiasm, but whose personality he found peculiar. They connected over ideas that would later appear in some of Wiener's first publications, in which Wiener rejected Whitehead and Russell's attempts to construct mathematics as a complete and logical system, and indeed any philosophy that sought final and certain knowledge. Writing about *Principia Mathematica* in 1913, Wiener saw it as "unlikely that such an amplification of Mr. Russell's sets of postulates would be possible" (Conway and Siegelman 2006, p. 28). Of Russell the man, Wiener wrote in a letter to his father, "He is an iceberg. His mind impresses one as a keen, cold, narrow logical machine, that cuts the universe into neat little packets, that measure, as it were, just three inches each way" (Conway and Siegelman 2006, p. 26).

Wiener used more measured language in his philosophical papers, which revealed to Eliot both the similarity of their convictions and a language in which to articulate them. Eliot received these papers over Christmas dinner in 1914, one of them entitled "Relativism." According to Pesi R. Masani (1985), who was not only one of Wiener's collaborators but also collected his writings after his death, "Relativism" and several other papers from the same time period showed the beginnings of Wiener's cybernetic thought. A key feature of cybernetics is the rejection of a deterministic view of the universe, in which absolute laws govern how it unfolds, in favor of the idea that only the probability of any physical state can be known. The relativism Wiener proposed in 1914 was an argument against philosophical absolutism and the impossibility of clear and total knowledge of reality: "The true object of our human thought is *not* the completely real, and all reality that we know is relative and partial" (p. 55).

"Relativism" seems to have had made a particularly strong impression on Eliot. What Eliot derived from Wiener was that philosophy has its roots in making sense of our ordinary experiences of reality, but its attempts to transform these experiences into complete theories can ultimately be nothing more than distorting. As Eliot wrote, "Almost every philosophy seems to begin as a revolt of common sense against some other theory; and ends—as it becomes itself more developed and approaches completeness—itself becoming equally preposterous to everyone but its author" (p. 74). Wiener's letters with Eliot suggest that they had long face-to-face conversations about the ideas presented in "Relativism," and much more, but sadly these are not recorded.

It is through these discussions that the possibility of a striking and unexpected conjunction becomes visible. Eliot's attraction to Wiener's ideas was perhaps rooted in Eliot's slightly longer interest in eastern philosophy. His 1922 poem "The Waste Land" famously ends with a Sanskrit mantra—"Shantih Shantih Shantih"—and reflects his studies of Indic philology at Harvard from 1911 to 1914. During the same time, Eliot had his first exposure to Japanese thought. In the 1913–1914 academic year, Eliot had the "mind-bending" experience of listening to the first lectures at Harvard on Japanese Buddhism and literature, given by a pioneer of religious studies in Japan, Masaharu Anesaki of the Imperial University of Tokyo. Eliot audited these lectures, intently taking notes which contained comments that would have been appropriate appearing on Wiener's manuscript: "Everything is interrelated …The views that the world exists, or not; both are false; the truth lies in the middle, transcending both views" (Crawford 2015, pp. 326–327). Having first met Wiener sometime between 1911 and 1913 at Harvard (Wiener 1985), and again at Cambridge University around the Christmas of 1914, when he and Wiener would have discussed Wiener's "Relativism" paper in person, it is easy to imagine Anesaki's lectures entering pivotally into their conversation.

I have not yet found documentary evidence of such a conversation at the moment, but in the fall of the following year (1915), Wiener was appointed a docent lecturer of philosophy at Harvard, a one-year position which at that time was granted by request to recent Harvard doctoral graduates. By then, Anesaki had returned to Japan, but his colleague, the Japanese Sinologist Unokichi Hattori, had been appointed his successor to lecture on "Japanese Literature and Life." Hattori gave the first lectures at Harvard on Confucianism, and with Anesaki, helped to establish what is now the Harvard-Yenching Library. Hattori would subsequently go to China, where he would become a key figure in establishing teaching schools under Japanese administration, as well as lay down the foundations of modern psychology in China, based on Japanese translations (Harrell 2012). In conjunction with his own lectures on mathematical philosophy, Wiener was employed as an assistant to Hattori for the duration of his visit to Harvard.

In the published literature, Wiener's relationship with Hattori is only mentioned twice. The first instance is in Wiener's second autobiography, where he devotes several lines to explaining the origin of his interest in "Oriental civilizations" in his work with Hattori, and his relationship with Chinese philosopher Chao Yuen Ren, with whom he often went hiking during that same year (Wiener 1953). Chao, subsequently, would become a noted linguist, and participate in the seminal Macy meetings on cybernetics some years later (Kline 2015). The other mention is by his Japanese translator and one of his first doctoral students at MIT, Shikao Ikehara, who noted in a publication from 1983 the impact that assisting a Japanese philosophy professor had on Wiener's thought, without further elaboration (Ikehara and Hirota 1983).

The effect of these experiences on Wiener and cybernetics is difficult for me to establish concretely. Wiener would hardly mention Asian philosophy of any kind in his writings, although his philosophical publications in general also essentially stopped for a long period beginning in 1916, when his attention moved to mathematics, and eventually, to the control engineering problems that led directly to cybernetics. But in contrast to other accounts of the history of cybernetics, which place an emphasis on Wiener's work at MIT during World War II—on predictive systems for anti-aircraft artillery—as the spark that led to the development of cybernetics (Edwards 1997; Galison 1994), attention to his earlier philosophical career may offer a richer, if not alternative, account of cybernetics.

While my evidence at the moment is circumstantial, it is clear that Wiener's cybernetics was not only established "explicitly in the experiences of war," as Peter Galison (1994, p. 263) has argued. It is likely that philosophical questions that were in the air of the pre-World War II North Atlantic mixed in fortuitous ways in the first moments when Asian thought was being legitimated and institutionalized in the intellectual centers of the United States and England. To clarify, however, my claim is not that cybernetics is originally Asian or that it is simply philosophy by another name, but that when considering the conditions in which it was born, we cannot discount the presence of intercultural and interdisciplinary interactions. These are interactions that crossed mathematics and philosophies both Western and Eastern, and which would eventually ripple out through cybernetics, into fields as diverse as computer science and engineering, neuroscience, business management, political governance, and New Age spirituality (Medina 2011; Hayles 1999; Pickering 2010).

An important core element that made the development of the field possible was the sustained exploration by Wiener of certain questions about order, uncertainty, and human value, as those questions were moved and translated from discipline to discipline. When we include such movements in our accounts of cybernetics, we can understand how it was more than simply the result of an attempt to answer a technical problem; it was also part of a broader inquiry into the nature of order, knowledge, and logic that drew from diverse disciplinary standpoints.

The Ecology of the Contemporary Moment

Today, it is difficult to imagine Whitehead and Russell, let alone Confucius or Eliot, as core readings in a course on information theory or control engineering. But a close examination of the history of cybernetics makes clear that these exclusions are not necessary because they are irrelevant to the core concerns of these subjects. Indeed, it is difficult to deny the value and productivity that Wiener gained by being a philosopher, then a mathematician, and then an engineering scientist during a moment of internationalization in the humanities. These exclusions persist, however, because of the essentialist misrecognitions between H&SS and STEM mentioned earlier.

These exclusions have two consequences that I would like to highlight. First, the relegation of H&SS to the other side of an absolute divide from STEM impoverishes our ability to imagine what science and technology are for. Lack of attention to these seemingly "secondary" interests of scientists and engineers may encourage us, as well as our students, to look upon the work that scientists and engineers do in terms that are either too abstract—to increase our knowledge of nature—or too concrete—to achieve some aim "X." This is a form of thinking that leads easily to the use of such "secondary" interests as "mere" tools, when they are also ways to pose and explore crucial questions about what kinds of societies should be created. The further consequence of this is that major differences in research methodology and approach—experimentation versus observation, for instance, or statistical versus qualitative analysis—are taken as definitive markers of the boundaries between fields, occluding what may be shared interests in questions of social, economic, or ethical value.

Second, this exclusion helps persuade people that what is of interest to those in their field has little overlap with the interests of people in others. Such characterizations of the disciplines do not correspond to the actual practices of many researchers. At the same time, they lead those who might adhere to these representations too strongly to ignore a wealth of knowledge and ideas that inspired their predecessors, and continue to inspire some of their colleagues.

This second point is one that applies as much to students of the humanities and social sciences as it does to students of science and technology. The extent to which modern and classical studies of society and culture have been influenced by ideas from the STEM fields is both striking and underappreciated. Limiting myself to the view from cultural anthropology, the presence of cybernetics is apparent in areas where it might be expected, such as posthumanist theory, but also in linguistic anthropology, the anthropology of religion, and the anthropology of ethics and morality. Structuralist and post-structuralist anthropology similarly bear the marks of cybernetics and information theory. Close and sustained attention to what scientists and engineers do and think is an essential stimulus for humanists and social scientists to understand the diverse forms that human societies and cultures can take.

Conclusion

Returning to the anecdote with which I began, I hope it is clear that the boundary between STEM and H&SS fields presumed by our common sense is not one that is as solid or as total as we assume. This is the case when viewed through a historical lens, as I have offered above. This also leads to the unsurprising recommendation that STEM students should learn more humanities and social sciences, perhaps with the addition that there are a wealth of things to be learned from the history of development and discovery in any number of STEM fields.

But it also leads to a problem for H&SS fields in the current moment. If, as I have argued, the forms of interaction and exchange among H&SS and STEM fields are of a rather subterranean variety, then their value is not easily recognized as emerging from transdisciplinary exchange. They can take a long time to bear fruit; any mention of these interactions may disappear from the journal articles, books, and even historical accounts of scientific discovery or technological innovation that constitute academic capital. If Eliot and Wiener had been junior colleagues in a university, how would the importance of their Christmastime conversations have been recognized by their institution or their other colleagues? This is a value that is as intangible as it is far-reaching. It passes through boundaries, but is overlooked precisely because it does not always need to announce its presence with a knock at the door.

It is further notable that Wiener's philosophical investigations were neither on questions that had any direct or instrumental relation to the scientific or engineering questions of his day, nor were his influences particularly concerned with such questions. I would speculate that this indicates the importance of maintaining certain disciplinary boundaries, at least institutionally, for the academic value of finding new ways to cross them.

Universities in Japan and elsewhere continue to face the difficult challenge of how to articulate the value of academic research in all its variety, while caught within a current that pushes them toward quantification and ranking. Evolving ranking methodologies and the convergence of H&SS and STEM fields on problems of common interest may prove to be promising and positive developments for universities with a broad research mandate. However, the problem remains of making explicit the kinds of value that, for instance, various kinds of philosophy had for the information age. Faced with this problem, but armed with a historical awareness of interdisciplinary and intercultural interactions, universities and educational policymakers should recognize that STEM and H&SS are not walled gardens, and neither are they isomorphic or convergent. They are part of an ecology of knowledges in which the growth of each species depends on its interactions with the rest.

References

Abraham, Itty. 2006. "The Contradictory Spaces of Postcolonial Technoscience." *Economic and Political Weekly* 41 (3): 210–218.

Bloor, David. 1991. *Knowledge and Social Imagery*. Chicago and London: University of Chicago Press.

Bourdieu, Pierre. 2004. *Science of Science and Reflexivity*. Translated by Richard Nice. Chicago: University of Chicago Press.

Conway, Flo, and Jim Siegelman. 2006. *Dark Hero of the Information Age: In Search of Norbert Wiener the Father of Cybernetics*. New York: Basic Books.

Crawford, Robert. 2015. *Young Eliot: From St. Louis to the Waste Land*. London: Vintage.

Edwards, Paul N. 1997. *The Closed World*. Cambridge: MIT Press.

Galison, Peter. 1994. "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision." *Critical Inquiry* 21 (1): 228–266.

Gieryn, Thomas F. 1983. "Boundary-Work and the Demarcation of Science from Non-Science: Strains and Interests in Professional Ideologies of Scientists." *American Sociological Review* 48 (6): 781–795.

Harrell, Paula S. 2012. *Asia for the Asians: China in the Lives of Five Meiji Japanese*. Portland, ME: MerwinAsia.

Hayles, N.K. 1999. *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. Chicago: University of Chicago Press.

Ikehara, Shikao, and Osamu Hirota. 1983. *Jōhō Riron Nyūmon: Jyōhō Kagaku No Tanjyō to MIT*. Tokyo: Keigaku Shuppan.

Kline, Ronald R. 2015. *The Cybernetics Moment: Or Why We Call Our Age the Information Age*. Baltimore, MD: JHU Press.

Latour, Bruno, and Steve Woolgar. 1979. *Laboratory Life: The Social Construction of Scientific Facts*. Beverly Hills, CA: Sage.

MacKenzie, Donald. 1978. "Statistical Theory and Social Interests: A Case-Study." *Social Studies of Science* 8 (1): 35–83.

Masani, Pesi. 1985. "Introduction and Acknowledgement." In *Norbert Wiener: Collected Works with Commentaries. Volume IV*, edited by P. Masani. Cambridge: MIT Press.

Medina, Eden. 2011. *Cybernetic Revolutionaries: Technology and Politics in Allende's Chile*. Cambridge: MIT Press.

Pickering, Andrew. 2010. *The Cybernetic Brain: Sketches of Another Future*. Chicago: University of Chicago Press.

Polanyi, Michael. 1962. "The Republic of Science: Its Political and Economic Theory." *Minerva* 1 (1): 54–73.

Traweek, Sharon. 1988. *Beamtimes and Lifetimes: The World of High Energy Physicists*. Cambridge, MA: Harvard University Press.

Wiener, Norbert. 1953. *Ex-Prodigy: My Childhood and Youth*. Cambridge, MA: The MIT Press.

Wiener, Norbert. 1985. *Norbert Wiener: Collected Works with Commentaries. Volume IV*. Edited by P. Masani. Cambridge: MIT Press.

CHAPTER 6

Developing Global Competencies Through Interdisciplinary Studies: Why Collaboration Is Important Between STEM and Non-STEM Students

Aki Yamada

Introduction

Modern globalization has become an important aspect of higher education policy and continues to play a significant role in policy reform. Globalization encompasses a transnational flow of political, economic, and cultural ideologies and values. It is the "product of the emergence of a global economy, expansion of transnational linkages between economic units creating new forms of collective decision making" (Torres 1998, p. 71). Globalization made waves in education as massification of higher education allowed students to study abroad. Philip Altbach (2013, p. 21) notes, "Mass higher education now forms a worldwide

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*,
International and Development Education,
https://doi.org/10.1007/978-3-319-98666-1_6

phenomenon. Enrollments constitute more than 150 million worldwide, having increased by 53 percent in just a decade." Acquiring and developing talented and competitive students requires international student mobility. Previously, politics, economy, and history were catalysts for migration. Altbach and Knight (2007, p. 290) define globalization as the "economic, political and societal forces pushing twenty-first century higher education toward greater international involvement." Modern migration is now also motivated by educational policies, rapid globalization, and reforms in the policies and practices surrounding migration control. Research, teaching, learning and advertising at home and abroad became focal points for universities that strive for excellence. Increasing globalization has led to a modern focus on "global citizenship," the notion that individual development, education, and utility is no longer constrained to national boundaries. UNESCO's (2015, p. 14) Global Citizenship Education report elaborates on the term, stating, "Global citizenship refers to a sense of belonging to a broader community and common humanity. It emphasizes political, economic, social and cultural interdependency and interconnectedness between the local, the national and the global" tiers. Higher education institutions are confronting the challenge of growing global citizenship in students, and competencies in the twenty-first century.

Amidst these changes is a rising demand for students to enter science, technology, engineering, and math (STEM) fields, which offer high-quality jobs that stimulate economic development and fulfill human capital needs in these sectors of industry. STEM fields comprise majors ranging from chemistry, physics, mathematics, engineering, statistics, and beyond. Advances in STEM research and development are core to economic growth and the creation of new industries, which manifest themselves in the products and technologies that we use in our daily lives. In the context of globalization, STEM students are now expected to develop a broad set of competencies so that they can operate and compete internationally and be prepared to work in interdisciplinary teams to solve real-world problems upon graduation.

Given the importance of globalization and STEM development in ongoing global higher education reform, this chapter will examine these trends and how Japanese higher education reform is tackling the challenges they present. Japanese government policy directives and individual university programs are turning toward new approaches in internationalization and the development of global competencies that pose challenges to the traditional Confucian methodologies typical of East Asian education. The new era of student mobility forced Japanese higher education to balance retaining domestic enrollments while attracting foreign students. Globalization and a knowledge-based economy and society are now the focal points of new degree programs in Japanese universities. This entails global human resource development strategies that foster students possessing international linguistic and communication skills and an understanding of diverse cultures (Yonezawa 2014, p. 39). The University of Tsukuba's Empowerment Informatics graduate program emphasizes the development of students possessing outstanding interdisciplinary and international abilities and is used as a case study to demonstrate this new direction of STEM education reform in Japan.

Globalization and STEM Demand

Change brought about by modern globalization has been a key factor informing the direction of higher education policy. Massification of higher education and increasing demand for talented workers in STEM fields have led to strong global competition in the education sector. Per a 2013 OECD report, from 2000 to 2011 the number of international students has more than doubled. Countries competing in a global economy and now transition to global knowledge-based and technology-based societies. National governments and education systems see STEM as the driver for economic development and international competitiveness in today's knowledge-based society. For example, the US Congress Joint Economic Committee (2012) notes that approximately half the US economic growth in the last 50 years was driven by productivity gains due to technological innovation. Many countries have adopted measures to focus on increasing STEM student diversity and matriculation. Market forces drive a comparatively strong demand for STEM workers. Between 2000 and 2010, US STEM employment growth tripled as compared to non-STEM fields. Also, it is predicted that from 2008–2018 STEM employment will continue growing at almost double the rate of other fields (US Department of Commerce 2011). As STEM demand has increased globally, there are new international opportunities for students who possess the appropriate skillsets.

STEM fields exemplify the growth of a knowledge economy and the changing demands for university skills worldwide. As per a 2015 IIE Open Doors report, 44 percent of international students in the United

States during 2014–2015 were studying in STEM fields (Institute of International Education 2016). The rising importance of these fields is a major trend in both the United States and Asia, but especially in Japan. Growing demand for STEM field workers and more attention on globalization have started to reshape the mission of higher education STEM programs specifically. It is apparent that STEM education reform is indispensable for responding to modern global economic challenges, the need for integrated and flexible knowledge and skills, and the solutions to global technological and environmental problems (Fan and Ritz 2014; Yamada 2017, p. 15). Higher education institutions must now adapt and ensure that student learning, assessment, and curricula are updated to reflect significant changes in modern societal demands. Based on the need for global competency, traditional Japanese undergraduate and graduate engineering programs are now introducing aspects of internationalization, development of collaborative problem-solving skills, and new courses that challenge students to develop both technical and non-technical skills and knowledge. While STEM fields have traditionally focused narrowly on providing graduates with specialized technical knowledge and skills, they are now also seeking to develop soft skills in global competency, teamwork, leadership, and problem-solving abilities to supplement primary field studies (Ragusa et al. 2014; Yamada 2017).

Globalization paired with changing socio-demographics and technological advances, ushers change in engineering's role in society (Ragusa et al. 2014, p. 1). In turn, higher education institutions are forced to ensure that student learning, assessment, and thus curricula is sought to reflect significant societal changes (Yamada 2017, p. 15).

STEAM: The Rise of a Symbiotic Relationship

While STEM fields are now in demand, there are benefits in STEM and non-STEM students working together in programs that emphasize interaction between the arts and engineering fields. Incorporating the arts in program personnel and content has led to the acronym "STEAM." The Rhode Island School of Design coined the term STEAM as it moved to establish art and design as a first-class citizen of US STEM educational policy (Daniel 2015, pp. 34–36). Neighboring universities like MIT closely followed suit by establishing STEAM programs. "Pedagogically, both art and engineering education lend themselves to problem-based learning (PBL), a way to motivate and integrate authentic learning in a discipline. PBL develops students' higher order thinking skills as they investigate ill-defined problems drawn from real life situations including aesthetic inquiry that is explicitly included in art curriculum" (Bequette 2012, p. 44). To cite an example of this, Lynne A. Kvapil of the University of Cincinnati demonstrated the application of STEAM field knowledge to create comprehensive and compelling grant proposals for archaeological excavations. Field archaeology, a multidisciplinary field, requires broad knowledge of history, empirical and qualitative methodology, natural sciences, engineering, and management (Kvapil 2009, pp. 45–52). Kvapil used PBL projects to force students to create competitive proposals for a grant to excavate a site in Northern Greece. By combining teacher-based assessment with peer-based assessment, students were motivated to create high-quality work products. To remove bias, the scenarios assigned to each group were high fidelity fictions, pulling in artifacts (pictures of objects, sites, etc.) from unrelated work. "Crossing boundaries between arts and science is predicated on the perception that these areas can meld fluidly together, and that a synergistic relationship may result" (Bequette 2012).

By posing PBL as a science one can break down the invisible barrier between STEM and non-STEM majors. "By emphasizing the process of science, rather than the inundation of specific facts, we can eliminate the fear of science that many students bring with them…Science is, in fact, a problem-solving discipline, and we must shift the paradigm from the accumulation of facts to problem-solving, and PBL can help accomplish this" (Keller 2002, pp. 272–281). Keller designed an introductory "Scientific Methods" PBL-based course for non-STEM majors and demonstrated that increased instructor creativity engages students and leads to greater understanding of the nature of science and its ability to address real world problems encountered in everyday life. Finally, the pervasiveness of PBL in both STEM and non-STEM classroom settings helps remove perceived barriers to entry in multidisciplinary programs, as the methodology is the same. Integration of the arts and practical learning helps prepare students to develop skills needed to work in real-world situations, without the artificial barriers compartmentalizing different fields that higher education students often experience.

The University of Tsukuba, Empowerment Informatics Program

Given the new demand for globally competent STEM students with interdisciplinary ability, Japanese education programs are looking toward new approaches. "The University of Tsukuba's Empowerment Informatics Program (EMP) will be used as a case study where Western-style courses introduce student-centric discussion, debate, and collaboration, seeking to prepare Japanese students with additional soft skills and the communication ability needed to operate in less hierarchical international contexts" (Yamada 2017, p. 18). The EMP program is sponsored by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT), and is designated as a leading graduate program in Japan. The University of Tsukuba was selected as a member of MEXT's "Top Global Universities" program, which aims to develop the internationalization of Japanese universities through English programs and extensive recruitment of and support for international students and faculty (MEXT 2014a, b, 2015). As a leading university and program, it makes for an excellent case study, representing the goals and direction that Japan's higher education system is working toward. The University of Tsukuba's EMP has paid careful attention to the trends and goals of Japan's higher education, as prescribed by MEXT, from multiple angles, including teaching, administration, student affairs, and student perspectives.

In a 2013 interview, the former Minister of Education and Science, Hakubun Shimomura, commented on the critical state of Japan's higher education: "Japanese universities are like isolated ivory towers. Their refrain has long been 'freedom of education and research,' but you suddenly realize they have been unable to cope with today's realities. Few are globally oriented, and few are in sync with the needs of today's society at home" (Tanikawa 2013). Since the rise of globalization and the increasing desire for the creation of world-class universities, Japan's higher education reform movements are adapting to these new trends in a manner that is appropriate for its culture and society. To ensure that quality education meets the needs of society, Japan's higher education institutions have been forced to embed learning outcomes into their curriculum. Guiding student outcomes, the EMP focuses on three sets of abilities that prepare students for their future career path, whether domestic or international:

1. Frontline: The ability to solve problems in the academic, industry, and public spheres.
2. Presentation: The ability to communicate effectively and convey the nature and importance of research achievements.
3. Interdisciplinary: The ability to consider issues from multiple perspectives, to see the "big picture," and to approach issues with creativity and innovation.

These three points form the core of the research abilities that the program values and seeks to develop in students in preparation for their future careers. Throughout its curriculum, the program uses these elements as important measures of quality for assessment and learning outcomes.

The EMP seeks to integrate engineering and social science fields to produce graduates with well-rounded skill sets. Aligning with the STEAM education model, students from both engineering and art backgrounds study together and collaborate while developing projects with real-world applications. Furthermore, the program equips graduates with highly developed skills and knowledge that can be transferred directly from the university to the workplace and society at large. Thus, in addition to knowledge and technical ability, courses incorporate teamwork and problem-solving, and undertake "Human Resource Development," by teaching communication, leadership, and global competency skills. Figure 6.1 shows the goals of the Human Resource Development in the EMP program. In order to polish skills in frontline, presentation, and interdisciplinary abilities, the program requires students to acquire knowledge from both their primary field and other interdisciplinary field studies.

The EMP program is quite unique in Japan, in its integration of arts and social sciences with its engineering studies. By choosing the incorporative STEAM approach, students develop interdisciplinary skills through the structural design of the program. With increasing globalization and fast-paced social change, higher education must strive to match the changing needs of society and industry in a timely manner. As Japan faces a diminishing and aging population with fewer college entrants and limited natural resources, it must strive to maintain competitiveness by improving quality, productivity, and creative innovation. Japanese higher education is shifting to prioritize policy and curricula that reflect the needs of society, leading to human resource development goals to match these needs. Thus, an additional measure of the quality of education is a

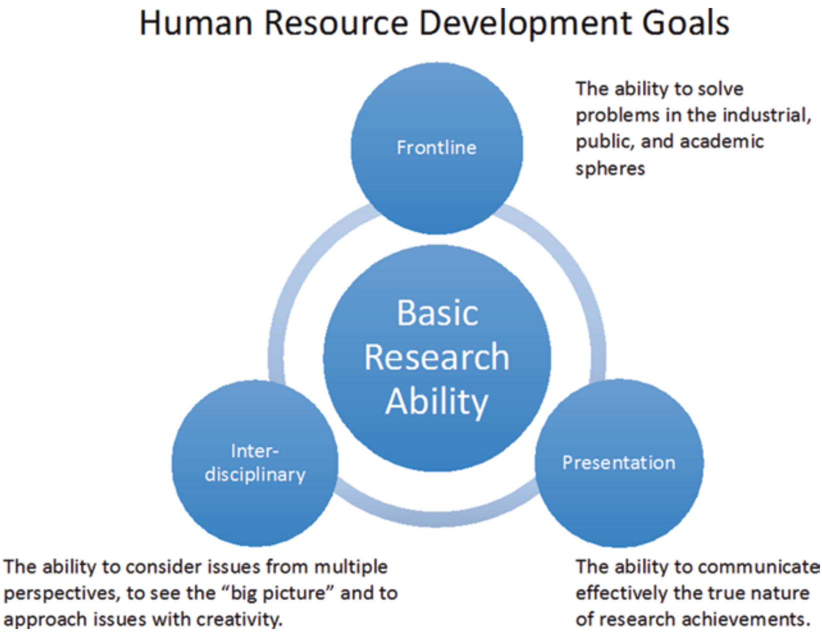


Fig. 6.1 Human resource development goals of the empowerment informatics program

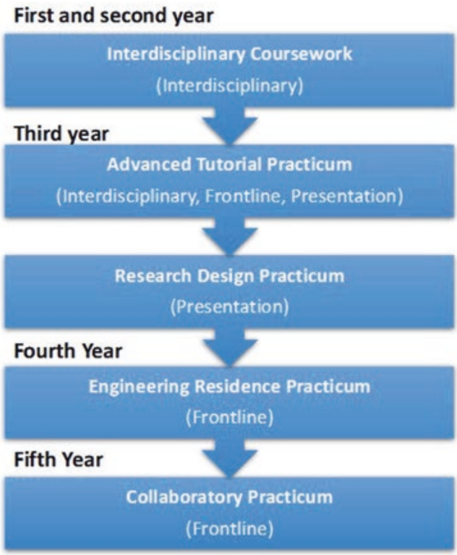
graduate’s development of skills and knowledge that can be transferred to the workplace and meet the demands of Japanese society. Japan’s Science and Technology Administration’s 5th Basic Policy Report calls for strong linkages between academia, government, and industry to ensure a system of human resource development that can meet these needs (Council for Science, Technology and Innovation 2016).

To cultivate graduates to lead Japanese industry in collaboration, innovation, and entrepreneurship, policy directives suggest that technical fields must additionally teach knowledge in the humanities and social sciences. Interdisciplinary studies are valued for the development of critical thinking, a broader perspective from other fields of study, and the ability to translate ways of thought between different fields. The addition of interdisciplinary studies provides a broad range of knowledge and skills that can increase industrial productivity and collaboration between the natural and social sciences.

Despite the EMP's focus on informatics, information processing, and engineering information systems, graduate students are required to take interdisciplinary studies to develop their aptitude to consider issues from multiple perspectives that are based on profound knowledge. By having students study outside their field at the graduate level, the program aims to develop each student's frontline ability, which connects to entrepreneurship, another important skill for the new twenty-first century global citizen. Students are expected to develop their skills to be able to communicate and make approachable presentations for audiences who have little knowledge of their specialized fields. In doing so, students improve their ability to appeal to different audiences in a variety of settings, including idea-sharing, academic grant applications, and the task of gaining the support of prospective investors and sponsors.

Two ways in which the EMP illustrates this development of interdisciplinary skills are the "Lab Rotation" and "Project-based Research" courses. In the Lab Rotation course, students engage in short-term work in laboratories engaged in various fields, such as medicine, neuroscience, art, creative/media art, and psychology. Despite not necessarily having experience in the fields and laboratories they join, students gain important exposure to functional real-world working environments, and acquire a broad range of knowledge and experience. By working in these interdisciplinary environments, graduate students meet scholars and researchers from other fields, gain insights and knowledge that they can bring to their own field, and acquire skills and expertise that will lead to future collaborations. The Project-based Research course, which is a sequence course with Lab Rotation, allows graduate students to work in a team and undertake work in a project-centered pedagogical style. The goal of this class is for each graduate student to possess and assert control over their research from start to finish. Students propose the concept for their project, persuade their team and faculty to support their choices, purchase materials, carry out the project, and finally present it in public for demonstration and feedback. Students form teams with other students from different fields to supplement each other's strengths. For example, engineering majors may find themselves implementing systems conceptualized and designed by artists. Teams also mix domestic and international students, adding additional perspectives and dimensions of culture and communication to their collaborative work. Project development and outcomes are guided and assessed through public demonstrations and evaluations from interdisciplinary faculty and experts from

Fig. 6.2 EMP special curricula



industry. These special curricula inside the EMP aim to help students to see their work through multiple perspectives that bridge academia, field research, and society, as illustrated in Fig. 6.2.

The EMP places high value on practical skills that can be applied in the workplace. The program is tightly coupled with industry participation and feedback from major Japanese corporations, such as Panasonic, Nissan, Hitachi, and NEC. During the final year, the curriculum is divided, with a focus on interdisciplinary coursework, advanced tutorial studies, and a research design practicum. To ensure the development of the ability to transfer skills to the workplace and beyond, the EMP has several key required practicums where students learn outside the academic campus: the research design practicum, the engineering residence practicum, and a collaborative practicum. The first practicum is the research design practicum, where students learn research management from professionals in the arts, medicine, business, and various companies. In their engineering residence practicum, students utilize their frontline ability to carry out a six-month collaborative research project with a company. The collaborative practicum has students spend three months utilizing interdisciplinary abilities to prepare research proposals and work with laboratories specializing in different disciplines. These hands-on opportunities outside the classroom and in working conditions have students use the skills and knowledge they gained from the program and apply them in a real-world team setting. These opportunities to work in settings beyond the university are another important element in the program, since global citizenship skills and global competencies are intended to extend beyond classwork and the academic environment. To develop workplace skills and foster leadership, it is also important for students to bridge and transfer their academic learning to the workplace. In the next section, I will explain why the cultivation of global competency is indispensable for Japanese higher education and how it is embedded in the University of Tsukuba's EMP program.

Global Competency and the EMP Program

Amidst increasing globalization and student and workforce mobility on a global scale, Japan's higher education institutions are being challenged to produce global citizens who can succeed in an international knowledge-based society. A new metric for quality is to create students with the ability to not only succeed in Japan, but also to operate within the international community and become global leaders. "International intellectual contribution" and "mutual international understanding" have been raised as important key terms for Japanese higher education policies. New importance has been placed on significantly increasing the number of incoming and outgoing international students and faculty and developing the competitiveness of Japanese universities at the international level. Japanese universities are being challenged to improve their rankings among "world-class" universities. The metric for this goal is to have 10 Japanese universities in the world's top 100 by 2025.

In line with the goals set out by MEXT policy and trends in higher education, the EMP program promotes an international environment that aims to inculcate the global citizenship skills and working ability necessary for leaders in a modern globalized and knowledge-based society. To develop an environment of international collaboration and knowledge transfer, the EMP is open and accessible to foreign students by providing a curriculum that can be fulfilled through English coursework and institutional support. Coursework is provided in an international atmosphere where domestic and international students may enroll in the same classes and are encouraged to work together in their coursework and research projects. Some of the required courses of the EMP are taught only in English to further develop domestic students' linguistic skills. The integration of domestic and international students is another significant aspect of the program, stimulating the learning experience beyond a given student's specialized field of knowledge. Domestic and international students work together, and, through this interaction, they practice teamwork and problem-solving while gaining multicultural competency, intercultural maturity and sensitivity, and cross-cultural adaptability and awareness. In addition to actively accepting international students, the EMP integrates global collaboration in its faculty through participation from five major foreign universities representing the UK, France, the Netherlands, and the US. To be prepared to operate globally, the program provides opportunities for students to exercise global and intercultural competencies, "including a readiness to engage and effectively operate in unclear situations and different cultural contexts" (Ragusa et al. 2014, p. 3).

Cooperative problem-solving skills are important for global citizenship and international collaboration in the post-graduation workplace. While it is essential that students be capable as individuals, important values are gained through the ability both to contribute and share knowledge and skills with others, and to understand and incorporate ideas into a joint solution with other individuals from different educational and cultural backgrounds. Working in diverse groups provides students opportunities to practice expressing ideas and presenting them to others constructively and logically. Numerous studies have shown the importance of collaborative problem-solving in the twenty-first century workforce, which is transitioning from manufacturing to globally distributed teams working in information and knowledge services (OECD 2017). Furthermore, as technology allows for ease of international communication via email, videoconferencing and other means, virtual workplace collaboration will become more common in the future.

Student Engagement

The traditional foundation of the Japanese education system is quite different from that of countries like the United States, which often emphasize student engagement and utilize active learning in classroom discussions, debates, and projects. The EMP program seeks to incorporate active learning pedagogy to help develop global competencies that are often under-utilized in traditional Japanese classrooms.

The Japanese education system, along with other Asian education systems, has a strong Confucian basis that is known for its rote memorization and passive learning rather than active student participation in peer learning activities and group debate and discussion. Learning is often teacher-centric, where prepared lesson plans are strictly followed, and students learn material in a passive manner, without questioning or debate. The strength of this system is that students tend to excel in math and science subjects, and this is reflected in international evaluation metrics provided by tests such as the Programme for International Student Assessment (PISA), in which East Asian students from China, Singapore, South Korea, and Japan are consistently among the top scoring students in quantitative skills assessments (OECD 2013).Highly developed quantitative skills in science and mathematics can be considered as the greatest strengths of East Asian education. However, the passive Confucian learning model often overlooks the development of the soft skills that are valued in Western education and society, such as critical thinking, problem-solving, and spontaneous discussion and debate. Thus, students from East Asian schools have noted difficulties when trying to excel in Western environments, resulting in their contributions being overlooked or disregarded by those who are more assertive (Valiente 2008, pp. 73–91). To create strong leaders who can communicate and succeed in global environments, it is advantageous to introduce aspects of Western education to allow students to work within different cultural and social frameworks. Student-centered learning is cited as an important method to improve learning outcomes and student motivation, self-reflection, and engagement (European Association for Quality Assurance in Higher Education 2015; Yamada 2014). These educational practices, while by no means innovative in Western higher education institutions, are, for Japan, quite a new trend that only recently grew from the desire to provide higher quality education and satisfaction in Japan's higher education system.

To address the need for global competency and the ability to collaborate and lead internationally, Japanese graduate programs are starting to adopt a new hybrid model that combines aspects of the traditional Confucian educational model and a Western style of active learning. The EMP advocates active learning in three of the six core roles that are expected of students (i.e., "to take responsibility for their own learning and contribute to that of their fellow students; to work on the course materials individually and together with fellow students; and to participate actively and contribute to discussions and group work"). To develop active participation and student engagement, Japanese graduate students in the program are placed in group learning environments, which favor discussion and debate. In a departure from Japanese custom, these classes seek to create student-centered learning and teaching opportunities in that students play a leading role in class. Instructors of these classes facilitate coursework and discussion, but students are expected to actively analyze real-life issues, to take steps in response to problems, and to work out strategies to propose and present pragmatic and effective solutions.

While active learning is conducive to developing the skills required for global citizenship, it is also important for quality assurance purposes, where students and faculty engage in meaningful discourse and develop relationships associated with higher motivation, satisfaction, and educational outcomes. Previous studies have shown the benefits in engagement and learning outcomes when there is a faculty and student partnership in teaching and learning (Cook-Sather et al. 2014). To ensure quality education within Japan's higher educational institutions, it is important not only for students to possess an identity that makes them feel they are part of the university, but also for students, faculty, and staff to engage in a program with goals, embedded quality, and outcomes that result in growth and the development of talent that will enact real change and innovation.

Conclusion

Globally, higher education is proactively coping with new trends in globalization, internationalization, and the rising demand for STEM field graduates. STEM fields are widely acknowledged as essential for global economic competitiveness in the twenty-first century. Additionally, trends toward greater globalization and internationalization necessitate the development of leaders who have the skills and knowledge to operate, compete, and succeed at the global level. In addition to standard expectations for the development of individuals with advanced knowledge and technical capabilities, higher education reform seeks to enhance the quality of its graduates by introducing the development of the interdisciplinary knowledge and soft skills needed to adapt to ever-changing modern workplace needs.

Using the University of Tsukuba's Empowerment Informatics graduate program as a case study, this paper has outlined these trends and how they are being addressed in the context of Japan's higher education. As a STEM program incorporating collaborative work with non-STEM majors and providing interdisciplinary courses with faculty from diverse research backgrounds, the EMP program provides a glimpse of how Japanese STEM programs are responding to globalization. The EMP program, as part of the Japanese Government's Graduate Leading Schools program, effectively increases international student mobility and hybridization of STEM and interdisciplinary studies. To ensure education meets the rapidly changing demands on a workforce in a knowledge-based society, students are required to take interdisciplinary coursework, and collaborate and engage with students from other fields such as the arts and humanities. From PBL to problem-solving, both STEM and non-STEM field majors supplement each other with their strengths. Furthermore, coursework and projects entailing active learning ensure that students learn how to work effectively to identify and solve problems in diverse teams that include international students and students from different fields of study. To create graduates with the skills to compete and collaborate globally, the program is designed to attract international students and faculty who can integrate with domestic students. Fully funded scholarships, English language instruction, and overseas recruitment efforts have borne fruit in the form of international student enrollment. Utilizing this international community within the program and having a diverse student body working side-by-side, the program promotes cross-cultural understanding and the linguistic skills required for global citizenship and leadership. Most importantly, the EMP embeds these values in its management, so that they are consistently expressed in the program's goals, principles, and curriculum.

While addressing needs for global competency, human resource development, and student engagement, the EMP structure integrates aspects of quality assurance into its curriculum and policies. In addition to upgrading the program's quality educational outcomes in accordance with the indicators of quality prescribed by MEXT policies, the EMP program faculty also oversee quality. Faculty are responsible for checking on individual student outcomes annually, looking at the courses that they have enrolled in, and the events, conferences, and project demonstrations in which they have participated. Student presentations are also used to measure the quality of education and learning outcomes. Assessments and feedback on student and program outcomes are also sought from external entities, such as visiting international faculty and the program's participants from industry. Transparency is essential, since, as a leading graduate program, sponsorship and funding is provided by MEXT. Active student assessment is conducted throughout their progress in the program to ensure their outcomes meet the program's quality standards. Close participation and feedback from global academia and industry partners ensure education is relevant to career development and the needs of industry and society. As a leading graduate program in Japan, the EMP is representative of the direction of Japan's higher education reform and the drive for quality assurance amidst the current trends in globalization and STEM demand. Comparing other international programs systematically with Graduate Leading Schools in Japan may offer another dimension of analysis in program outcomes. More research and comparative analysis will be necessary once the ratings and reports from the EMP program's first midterm evaluation become available.

References

Altbach, Philip G. 2013. *The International Imperative in Higher Education*. Rotterdam: Sense Publishers.

Altbach, Philip G., and Jane Knight. 2007. "The Internationalization of Higher Education: Motivations and Realities." *Journal of Studies in International Education* 11 (3–4): 290–305.

Bequette, James W. 2012. "A Place for Art and Design Education in the STEM Conversation." *Art Education* 65: 40–47.

Cook-Sather, Alison, Catherine Bovil, and Peter Felten. 2014. *Engaging Students as Partners in Teaching and Learning: A Guide for Faculty*. San Francisco, CA: Jossey-Bass.

Council for Science, Technology and Innovation. 2016. "The 5th Science and Technology Basic Plan." Last Modified January 22, 2016. http://www8.cao.go.jp/cstp/english/basic/5thbasicplan.pdf.

Daniel, Alice. 2015. "Academic Toolbox: Full Steam Ahead." *ASEE Prism* 24 (7): 34–36.

European Association for Quality Assurance in Higher Education. 2015. *Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG)*. Brussels: European Association for Quality Assurance in Higher Education.

Fan, Szu-Chun C., and John M. Ritz. 2014. "International Views of STEM Education." In *Proceedings PATT-28 Conference*, edited by Marc J. de Vries. Last Modified 2014. http://www.iteea.org/File.aspx?id=39511&v=a2bd6f55.

Institute of International Education. 2016. "International Students by Field of Study, 2014/2015–2015/2016." *Open Doors Report on International Educational Exchange*. New York: IIE.

Keller, George E. 2002. "Using Problem-Based and Active Learning in an Interdisciplinary Science Course for Non-Science Majors." *The Journal of General Education* 51 (4): 272–281.

Kvapil, Lynne. 2009. "Teaching Archaeological Pragmatism Through Problem-Based Learning." *The Classical Journal* 105 (1): 45–52.

MEXT. 2014a. "National University Reform Plan (Summary)." Last Modified March 13, 2014. http://www.mext.go.jp/en/news/topics/detail/__icsFiles/afieldfile/2014/03/13/1345139_1.pdf.

———. 2014b. *Selection for FY 2014 Top Global University Project*. Last Modified September 2014. http://www.mext.go.jp/b_menu/houdou/26/09/__icsFiles/afieldfile/2014/10/07/1352218_02.pdf.

———. 2015. "Japans STI Policies Looking Beyond Mid-long Term." Last Modified January, 2015. http://www.mext.go.jp/en/news/topics/detail/__icsFiles/afieldfile/2015/07/03/1359554_1.pdf.

Organisation for Economic and Co-operative Development (OECD). 2013. *Education Indicators in Focus 14*. Paris: OECD.

———. 2017. "PISA 2015 Draft Collaborative Problem Solving Framework." Paris: OECD.

Ragusa, Gisele, Cheryl Matherl, and Sarah Phillips. 2014. "Comparison of the Impact of Two Research Experiences for Undergraduate Programs on Preparing Students for Global Workforces." *Proceedings for the IEEE Frontiers in Education Conference (FIE)*, 1–7. https://ieeexplore-ieee-org.libproxy.mit.edu/stamp/stamp.jsp?tp=&arnumber=7044297.

Tanikawa, Miki. "Japan's Education Minister Aims to Foster Global Talents." *The New York Times*. Last Modified August 25, 2013. http://www.nytimes.com/2013/08/26/world/asia/Japans-Education-Minister-Aims-to-Foster-Global-Talents.html.

Torres, Carlos A. 1998. *Democracy, Education, and Multiculturalism: Dilemmas of Citizenship in a Global World*. Lanham, MD: Rowman & Littlefield Publishers.

United Nations Educational, Scientific and Cultural Organization (UNESCO). 2015. *Global Citizenship Education: Topics and Learning Objectives*. Last Modified 2015. http://unesdoc.unesco.org/images/0023/002329/232993e.pdf.

U.S. Congress Joint Economic Committee. 2012. "STEM Education: Preparing for the Jobs of The Future." Last Modified April 2012. https://www.jec.

senate.gov/public/_cache/files/6aaa7e1f-9586-47be-82e7-326f47658320/stem-education---preparing-for-the-jobs-of-the-future-.pdf.

U.S. Department of Commerce. 2011. “STEM: Good Jobs Now and for the Future.” Last Modified July 2011. http://www.esa.doc.gov/sites/default/files/stemfinalyjuly14_1.pdf.

Valiente, Carolina. 2008. “Are Students Using the ‘Wrong’ Style of Learning?” *Active Learning in Higher Education* 9: 73–91.

Yamada, Aki. 2015. “Changing Dynamics of Asia Pacific Higher Education Globalization, Higher Education Massification, and the Direction of STEM Fields for East Asian Education and Individuals.” In *Redefining Asia Pacific Higher Education in Contexts of Globalization: Private Markets and the Public Good. International and Development Education*, edited by C. S. Collins & D. E. Neubauer (pp. 117–128). New York: Palgrave Pivot.

Yamada, Aki. 2017. “Japanese Higher Education Reform Trends in Response to Globalization and STEM Demand.” *Comparative and International Higher Education Journal.* https://gallery.mailchimp.com/cba3ded-f7646e76a7881fd1b1/files/026fe47e-1555-4753-8072-977fb367830d/JCIHE_Fall_2017.pdf.

Yamada, Reiko. 2014. “Gains in Learning Outcomes of College Students in Japan: Comparative Study Between Academic Fields.” *International Education Journal: Comparative Perspectives* 13 (1): 100–118.

Yonezawa, Akiyoshi. 2014. Japan’s Challenge of Fosterning “Global Human Resources.” http://www.jil.go.jp/english/JLR/documents/2014/JLR42_yonezawa.pdf.

CHAPTER 7

Not Just a Technical Problem: The Intersections of STEM and Social Science in Addressing Global Poverty

Christopher S. Collins

Introduction

Poverty is often measured by a crude line of less than 2 USD per day, which is set by the World Bank. As of 2012, almost 13% of the entire world population still lived below this extreme poverty line (World Bank 2017). Although there are limitations to the measurement of global poverty, it is a large enough indicator to draw the interest of global and regional development banks, bilateral and unilateral aid from governments, and research initiatives from companies, think tanks, and universities. Blending international development and university knowledge production led to a unique effort organized under a network established by the United States Agency for International Development (USAID). Hundreds of universities submitted applications to participate, and eight

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*,
International and Development Education,
https://doi.org/10.1007/978-3-319-98666-1_7

development labs at seven different universities were selected to utilize funds from a pool of 137 million USD. In a previous study of the eight development labs (at seven universities) funded by USAID, I focused on the role of higher education at large and, more specifically, the cultural architecture and potential impact of development labs on global issues related to poverty and social progress (Collins 2017). In this chapter, I focus in on the role of interdisciplinary work at the eight university development labs.

At the University of California, Berkeley, for example, the Development Impact Lab worked to open a new course of study for doctoral students and started a new academic publication entitled the *Journal of Engineering and Economic Development*. The efforts at this lab worked to combine social sciences with the technicalities of engineering. Although the work at Berkeley stands out as forging new academic territories, the effort at being interdisciplinary was a feature of the eight different labs in the study. Using qualitative methods, I interviewed key personnel, faculty, and students on site at each of the eight labs. The guiding question for this study was, what are the contours of intersecting disciplines at university-based development labs in an effort to reduce global poverty? In an effort to answer the question, this chapter includes an overview of conceptualizing interdisciplinarity, background on the study, and findings related to interdisciplinary work in the USAID-funded Global Development Labs.

Between Disciplines

The life cycle of science and knowledge production is both an evolution and a hierarchy. There are multiple factors weighing into the legitimacy and location of what is counted as knowledge. One contemporary example of the static and fluid nature of knowledge is in relationship to indigenous science. A case study of an indigenous serving university showed how knowledge developed in a laboratory could earn legitimacy that indigenous science did not have, even if it was the same fractal of understanding (Collins and Mueller 2016). Disciplines are part of a hierarchy that promotes the development of knowledge through some roughly agreed-upon standards and part of the hierarchy that builds a tyranny of expertise.

More practically, faculty jobs are increasingly billed as interdisciplinary, even within natural sciences. Jacobs (2009, p. 4) wrote a defense of disciplinary work, associated interdisciplinary work with specialization, and offered:

> If disciplines are not the suffocating cloisters their critics have portrayed them to be, what about the other side of the coin: whether interdisciplinarity is likely to achieve the goals that have been set out for it. Is an interdisciplinary structure likely to overcome division and provide a more synthetic understanding of our natural and social world?

Five years later, Jacobs (2014) wrote that interdisciplinary is too often equated with innovative: "The popular notion seems to be that the solutions to real-world problems require the insights of cross-trained researchers, or at least interdisciplinary teams" (p. 1). Fuller (2003), a strong proponent of interdisciplinary work advanced the idea that standard disciplines are really held patterns that are static and artificial whereas inquiry needs more space and the freedom to roam.

The problems addressed by science and knowledge production are increasingly difficult because of the size, nuance, complexity, and range such that it seems difficult to understand them in a disciplinary silo. As a result, the United States government-based funding through the National Institutes of Health and the National Science Foundation are continuing to offer specific grants that are focused on interdisciplinary work. Furthermore, the Committee on a New Biology (2009) published a book to make the case that in order to solve the greatest societal problems, disparate fields and subdisciplines need to re-integrate in order to have a greater understanding and impact on issues like health, food, energy, and the environment. The committee cited the Human Genome Project as a large-scale interdisciplinary approach that was conducive to the rigorous free inquiry of good science.

Graff (2015) offered an in-depth and extensive examination into interdisciplinarity and noted that it is "constructed by questions and problems of theory or practice, knowledge or conditions of living, and the means develops to answer those questions in new and different ways" and added that the interdisciplines themselves are fashioned from "elements of different disciplines to form distinct approaches, understandings, or contacts" (p. 5). Accordingly, the very notion of an interdiscipline is a historical construct. There is no homogeneity interdisciplines and no single path or model to successfully develop them. Graff also cited Heckhausen (1972) as including a range of possibilities for interdisciplinarity as including communicating ideas, a mutuality in organizing concepts, methods, data, language, or epistemic understanding.

Frodeman (2010), author of the *Oxford Handbook of Interdisciplinarity*, is an ardent supporter of the efforts of integration and argues that the silos of individual disciplines actually serve (intentionally or unintentionally) the function of avoiding fundamental responsibilities as to how knowledge can actually contribute to social progress, or in the case of this chapter, a decrease in global poverty. Graff (2015), however, considered these sentiments to be more ideological as opposed to substantive and wrote that it "simplifies the positions of scholars across disciplines and clusters of disciplines in an effort to justify certain forms of cross-disciplinary and multidisciplinary work" (p. 7).

Disciplines and Development

International development is a moving target. Not only do social problems change, but ideologies and approaches also change. Perhaps one of the most poignant examples is the disposition of the World Bank on primary versus higher education as it relates to individual rates of return in the 1980s and 1990s. Because primary education was thought to be a better investment based on the individual rate of return, higher education was systematically disenfranchised and often became a condition of disinvestment for a country to get a loan related to anything from building a road to a healthcare project (Collins and Rhoads 2010; Collins 2011). Furthermore, there is a spectrum of ideology related to theories of homegrown development (Easterly 2013) versus notions of technocratic development (Sachs 2005).

Sachs (2005) advanced and built upon a theory that a series of corrective actions related to wealthy country engagement with developing countries could lead to a serious reduction in poverty. This included technical formulas for the types of problems that needed to be solved, in addition to the amount of development aid that needed to come from wealthy countries. On the other side, scholars like Easterly (2013) maintained that development is a relatively new scheme that did not exist when current superpowers were rising to their position of dominance. If developed nations achieved a wealthy and powerful status through a series of actions, then it may be reasonable to assert that those steps are still relevant, including homegrown development, self-sufficiency, and human rights, which often gets overlooked as benefactors, technocrats, and dictators distribute humanitarian and development aid. If interdisciplinary work is called upon for innovative and problem-solving capabilities, what happens when the problem is a moving target?

Abbot (2001) maintained that interdisciplinary work is most often "problem driven" and that problems, of course, have a beginning and an end: "There is ample evidence that problem-oriented empirical work does not create enduring, self-reproducing communities like disciplines, except in areas with stable and strongly institutionalized external clienteles like criminology" (p. 134). As it relates to development—the life cycle of a problem applies to not only the actual issues of poverty and social progress, but also to the ideologies that drive a response to poverty. As a result, this study looks into eight primary sites where knowledge production at universities was leveraged to engage major global problems of development and the ways in which interdisciplinarity was used as a tool.

Methods

In an effort to explore a large, multimillion dollar grant project with sites all over the world, I used a broad case study design and approached the complex topic with specific contextual parameters (Flyvbjerg 2011; Yin 2003). The boundaries of the case I selected were the core institutions that were awarded a grant from USAID to be a development lab. Although many of the universities had numerous partner institutions and projects, I focused on the seven core universities that employed the primary investigators (PIs) for each grant. The guiding question for this subset of the larger study was, what are the contours of intersecting disciplines at university-based development labs in an effort to reduce global poverty?

Data Collection

Over the course of 18 months and with the approval of an Institutional Review Board, site visits took place at all seven universities that hosted the eight development labs (see Table 7.1). At each site, I engaged in interviews, informal conversations, tours, demonstrations, and meals with students, faculty, and staff, all of which informed my understanding of the labs. Participants were recruited through contacts listed on

Table 7.1 List of development labs

University	*Lab*	*Focus*
Texas A&M University	ConDev: The Center on Conflict and Development	The complications of land rights, asset growth, and other development issues emerging from conflict
Massachusetts Institute of Technology (2 labs)	International Development Innovation Network (IDIN) & Comprehensive Initiative on Technology Evaluation (CITE)	IDIN: The implementation of engineering innovations in developing societies. CITE: Comprehensive assessment of development technologies
University of California, Berkeley	Development Impact Lab	A blend of academic engineering and development to test and scale new technologies
College of William & Mary	AidData	Geocoding and tracking development spending and projects around the globe
Michigan State University	Global Center for Food Systems Innovation	To develop solutions for future critical global trends impacting food systems
Makerere University	Resilient African Network (RAN)	Discover, apply, and scale development technologies to enhance community resilience
Duke University	Social Entrepreneurship Accelerator at Duke (SEAD)	Growing companies that are effective health providers in critical developing areas

program websites, and an information sheet detailing the study. The nature of participating in the study and informed consent requests were distributed to participants. Each visit included interviews with the lab leadership, faculty, staff, and students that were coordinated in advance via email and typically through someone who acted as a gatekeeper or correspondent at the lab. I was also given the opportunity to listen to presentations, tour facilities where innovations were on display, and observe faculty and student work. I tested bicycle powered machines, solar pumps for farmers, and saw the ingenuity behind electromagnetic elements in blood tests for malaria. I also reviewed relevant documents (e.g., funding proposals, annual reports, monitoring and evaluation schemas, student papers, publicity notices, and academic publications). Each site visit was different, but provided an opportunity to learn about the key functions and cultures of the labs. The facilities were impressive and clearly high priorities at their respective institutions.

A total of 35 formal interviews were conducted (29 audio recorded and transcribed verbatim, 6 recorded through taking copious notes). Participants were asked open-ended questions about the nature of their work and the value of extension. To better understand how participants construct reality and think about the topics presented, each interview was flexible in format.

Analysis and Trustworthiness

The analytic strategy was inductive, deductive, and cyclical, as it was continually organized, reviewed, and coded (Creswell 2003). All interview transcripts, field notes, and memos were compiled into Dedoose, a qualitative coding program, to organize the data and to assist in the application of consecutive rounds of coding. The first step in the analytic process was to identify major patterns in the participant interviews (Yin 2003) that related to interdisciplinary innovations. The second phase of analysis was to identify unexpected and emergent themes and recode all of the data.

Throughout the data collection and analysis process, various measures were used to enhance the trustworthiness of the findings from my perspective as well as the perspectives of the participants. I had continued engagement with the overall case; I was physically visiting the sites for a total of 30 days over the course of 18 months, but I also kept track of press releases, publications, and program advancements at each lab, even when I was not physically on site. Drawing from Lincoln and Guba (1985), I employed multiple approaches to triangulation and searched for discrepant cases that ran counter to the dominant narrative of each theme. Triangulation of persons and perspectives emerged through interviewing faculty, staff, and students, with variety perspectives and roles represented by each group. The discrepant findings were generated as part of the inductive strategy. The presentation and discussion of contrary information was designed to promote reflection on the complex reality of different perspectives. The deductive strategy was explicitly linked to literature about interdisciplinary work.

Findings

The contours of interdisciplinary work in the development labs proved to be a salient theme emerging from the interviews. Although this chapter is primarily focused on the intersection of STEM and social sciences, I did not directly ask participants questions about the interdisciplinary work. As a result, the findings are truly emergent themes from the data collection. The first finding is about the connection between social problems and the possibilities of academic inter and multidisciplinary work as a facilitator of solutions. The second finding moves from the notion of intersections to a deeper level through a discussion of poly-epistemologies as it relates to a concept that participants termed the "co-creation" of knowledge.

Social Problems and Academic Solutions

> *Our project is really meant to be multidisciplinary*—Professor at a Development Lab

Development labs are designed to apply the best of what the university can produce to the biggest problems related to poverty and global development. In the sense that universities and development banks/agencies are in different lines of work, the development lab's project is cross-sectional. Within the development labs, one dominant theme was the intersection of disciplines—particularly STEM and social science. Knowledge produced in the academy is not considered mainstream and could be perceived as irrelevant to society at large. However, the academy also defines and maintains the boundaries of codified and legitimated knowledge. In relation to development labs, the multidisciplinary work emerged as a clear strategy to shape the academy and its ability to impact society. A faculty member at one of the lab's highlighted that the challenge of changing academic culture for the purpose of being relevant to the needs of society is much bigger than "attaching a microscope to a cell phone" and that there was much work to be done to "engage higher education…for the benefit of society" (Professor at a Development Lab).

As noted in the methodology, there are labs focused on food security, conflict, engineering, and many other topics. Most of the labs had some overt cross-disciplinary activity. One faculty member working in agriculture explained that it was challenging to think about the entire food system from growing, all the way to processing and marketing. He explained that in order to engage in such a broad range of work, "Think about coming up within divisions in the food systems that could be a wide range of different areas. It is broad because we are supposed to be a multidisciplinary center so we have got like five colleges involved" (Professor at a Development Lab).

Beyond what is happening at the university locations, the work of the development labs on project sites in communities included some rich descriptions of how needs assessment and potential impact was connected to interdisciplinary work. The following description by a researcher at a lab demonstrates the connection:

> We took a very technical attack on the problem of water quality and water supply in some areas. I was doing a lot of focus groups that introduced to people to understand what the story of water supply was in this particular community. It was unusual for engineering. It was very unusual. What emerged over time was that water supply wasn't just a technical problem. It was political and economic, but here we were promoting solutions from engineering departments. We were treating with hammers and nails. We just wanted to solve the water problem. We were designing water treatment devices at workshops to get the design right and all these things. People constantly told us that we have to walk the road to get the water supply. We [as a team] had not gone out. We were in a government office and we would wait outside until they gave us what we needed to survive in this place. The community was [upset] because of that. There were contentious systems at work including settlements and broken promises from the government. This was the context and we didn't see any of that. I think the reason that the project unfolded that way was because as engineers we were only trying to see the problems as technical problems and we just infused technology to solve the problem…I think now that as engineers we need to be supporting people's struggles to get access to the resources by providing technical tools, technical expertise, and mobilizing data to prove their point instead of focusing exclusively on technical procedures. (Researcher)

In this example, the same technocratic approach critiqued by Easterly (2013) prevented the team from being able to see the larger problem. Conversely, research teams with diverse disciplinary perspectives and co-collaborating with people embedded in the community can yield different results and open the door for spontaneous solutions and discovery.

In the academic environment, two of the development labs were working in very progressive ways to create new legitimate academic boundaries. The new space involved combining engineering with social science. One staff member at a development lab said:

> We call it development engineering as a discipline. It's sort of like bioengineering or environmental engineering. Over time we realized in academia that there's a new emerging set of principles that define a field or a subfield and we try to formalize that through courses, through textbooks, through bodies of work that exemplify the approach. We think that development engineering is beginning to achieve that status of being a subfield or subdiscipline. We're launching a Ph. D. minor for doctoral students in engineering but also in quantitative social science disciplines teaching them what we think … to use a tool kit of techniques that do help you develop innovations that are appropriate in low resource settings and I can talk more about that if you're interested and we're also funding a series of conferences, seminars, post-doctoral fellowships and other typical university activities focused in this new area. (Staff Member)

Because of the stagnant nature of the academy, creating a new space was difficult. The staff member went on to say that engineers have not "thought of themselves as interventionists although they definitely intervene through the introduction of technologies" (Staff Member). Furthermore, engineering professors have typically never had the opportunity or reason to file a human subjects' protection protocol. According to a team member at one of the labs, "very few of them are pushed in the research design to anticipate impacts and risks to human subjects even if they are going to be doing fieldwork and interviewing users" (Staff Member). As a result, the multi or interdisciplinary move required a change in culture.

Another researcher at one of the labs noted that focusing on engineering and development was a cultural change because of the realization that "we have not fully considered the users perception and behavior" (Engineering Researcher). In that particular lab, there was a project to work with faculty on farm-based solar water pumps and they worked closely with farmers and social scientists to refine the design of the pump. Researchers and staff members talked about a latrine project and the need to overcome cultural beliefs related to using a toilet and to consider the time, location, availability, strength, and size of individuals. A researcher defined development engineering as an "academic innovation designed to focus on the developing world" (Researcher). Even more progressively, the researcher identified that the products of development engineering should be "designed for the community" which was distinct from the desire for prestige that is often embedded in "colonized education systems" which meant that there was also a need for "decolonial engineering."

Poly-Epistemological

[We are] respecting communities enough to know that they can design solutions for their own problems—Development Lab Staff Member

Some development lab researchers demonstrated the pitfalls of the technocratic and tyrannical approach of expertise while demonstrating a level of epistemic humility. Other examples from the labs demonstrated an important step in cross-disciplinary interaction, claimed a decolonial stance, and pointed toward the importance of knowledge co-creation partnerships outside of the academy. Other faculty members exhibited more of a linear and singular source of expertise, one of which even expressed "pride" in the strength of being "unbiased, university branded experts that can talk about lessons learned for the field and rightfully or not, people listen to what we say" (Professor).

If the flow of knowledge is in one direction, there are knowledge producers and knowledge consumers. The comment from a development lab professor who spoke of pride associated with being "unbiased…experts" is an example of the mentality critiqued by Easterly's (2013) framework, and suggests a single direction on the flow of knowledge. When the academy promotes narrow definitions of what counts as knowledge and what will work for development it emits a technocratic expertise that can serve to alienate or even annihilate diverse epistemologies (Collins and Mueller 2016).

Beyond being cross-sector (development and academics), interdisciplinary (STEM and social science), there is also an issue of poly-epistemologies. The academy (in particular hard sciences) and the development industry (built upon economics and conditionalities) have a tendency to engage in tyrannical expertise. Within the development labs, there was a theme that emerged as a potential path to promote poly-epistemological openness. Although none of the participants used that phrase, many of the labs focused on co-creation of knowledge. In the case of development labs, co-creation was a term that is applied when an academic and someone from the community worked together on a project or innovation. In some labs, co-creation was a case of combining the work of high-level university scientists and thinkers applied in a development community setting to disrupt and contextualize the innovation. For example, a researcher from one lab noted:

> There is a lot of co-creation that happens. When we go to the villages the teams are supposed to work with the community members.… [Community members] find it empowering [to help] designing the solution. So there is a lot of empowerment that happens where respecting communities enough to be able to understand that they can design solutions to their own problems versus saying, "Oh, I know what is right for you. Here is how you should do this. Here is what is going to work." (Engineering Researcher)

In another example, a staff member recounted bringing a specific technology (like an oil press) to a community for the purpose of making a local resource a cash crop, and the community came back with ten recommendations on how the lab should improve the product. The staff member described the highlight of her trip as seeing university personnel "really working hand in hand with the community, which we call co-creation" (Staff Member). Other lab employees described similar sentiments. There were many comments about community engagement and truly listening to what people in the communities were saying about problems, solutions, and innovations.

The theme of co-creation is an important development practice and one that could serve to disrupt the linear tyrannies of expertise that evolve from the academy and development agencies. One researcher emphasized that the problems of society are "bigger than any one discipline." Another faculty member went to great lengths to describe how he had a "UN report that said lack of electricity is a problem for education so I designed a way to get electricity. We are coming at it from global statistics and then dropping it to a particular place. I think we need to reverse that…We are not supporting it. We are trying too much of a leadership role now" (Professor).

The theme of co-creation could potentially be a pathway to not only acknowledging but also demonstrating value in the diverse epistemologies and stored cultural knowledge in the communities where much development work takes place. The academy has too often taken knowledge developed in ancient practices and communicated through oral histories and recreated it in a controlled experimental environment. Only in the latter does the knowledge become legitimized, which is problematic when it comes to the ideas of expertise and development.

Conclusion

The larger work of the USAID-funded development labs shows an impressive body of outcomes and evidence. The connection between the diverse knowledges required to solve complex problems and the ability for universities to play a role in global development was quite profound. The guiding question for the study was about the contours of interesting disciplines in the work and impact of the development labs. Through rich examples in agriculture, engineering, and even healthcare, the development labs showed how hard sciences and STEM were incomplete when it comes to addressing poverty, social progress, and global development at large. Interdisciplinary work, while often tied to innovation, was a key component in universities and academic knowledge being made relevant to poverty. The concept of interdisciplinary work in STEM and global development should be expanded further to poly-epistemologies to prevent falling into the traps of tyrannical expertise. Recognition of knowledge stored in communities in developing regions and far outside the walls of the academy will likely be essential to understanding the world's biggest problems and therefore a prerequisite to developing solutions for those problems. Ignoring indigenous knowledges will render even the best interdisciplinary projects as perpetuating colonial views of education and expertise and further bifurcate the relationship of developed and developing regions as knowledge producers and consumers.

References

Abbott, Andrew. 2001. *Chaos of Disciplines*. Chicago: University of Chicago Press.

Collins, Christopher S. 2011. *Higher Education and Global Poverty: University Partnerships and the World Bank in Developing Countries*. Amherst, NY: Cambria Press.

Collins, Christopher S. 2017. "Development Labs: University Knowledge Production and Global Poverty." *The Review of Higher Education* 41 (1): 113–139.

Collins, Christopher S., and Robert A. Rhoads. 2010. "The World Bank, Support for Universities, and Asymmetrical Power Relations in International Development." *Higher Education: The International Journal of Higher Education and Educational Planning* 59 (2): 181–205.
Collins, Christopher S., and Kalehua M. Mueller. 2016. "University Land-Grant Extension and Resistance to Inclusive Epistemologies." *The Journal of Higher Education* 87 (3): 303–331.
Committee on a New Biology. 2009. *Biology for the 21st Century*. Washington, DC: National Academies of Science.
Creswell, John W. 2003. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. Thousand Oaks, CA: Sage.
Easterly, William. 2013. *They Tyranny of Experts: Economists, Dictators, and the Forgotten Rights of the Poor*. New York: Basic Books.
Flyvbjerg, Brent. 2011. "Case Study." In *The Sage Handbook of Qualitative Research*, edited by Norman K. Denzin and Yvonne S. Lincoln. Thousand Oaks, CA: Sage.
Frodeman, Robert. 2010. *The Oxford Handbook of Interdisciplinarity*. Oxford, UK: Oxford University Press.
Fuller, Steve. 2003. "Interdisciplinarity: The Loss of the Heroic Vision in the Marketplace of Ideas." Available at https://www.academia.edu/1161664/Rethinking_Interdisciplinarity..
Graff, Harvey J. 2015. *Undisciplining Knowledge: Interdisciplinarity in the Twentieth Century*. Baltimore, MD: Johns Hopkins University Press.
Jacobs, Jerry A. 2009, November 22. "Interdisciplinary Hype." *Chronicle of Higher Education*. Available at http://www.chronicle.com/article/Interdisciplinary-Hype/49191/.
Jacobs, Jerry A. 2014, May 27. "Why Disciplines Still Matter." *Chronicle of Higher Education*. Available at http://www.chronicle.com/article/Why-the-Disciplines-Still/146777/.
Lincoln, Yvonne S., and Egon Guba. 1985. *Naturalistic Inquiry*. Thousand Oaks, CA: Sage.
Sachs, Jeffrey D. 2005. *The End of Poverty: Economic Possibilities of Our Time*. New York: Penguin Books.
World Bank. 2017. *Measuring Poverty*. Washington, DC: World Bank. Available at http://www.worldbank.org/en/topic/measuringpoverty.
Yin, Robert. 2003. *Case Study Research: Design and Methods*. 3rd ed. Thousand Oaks, CA: Sage.

CHAPTER 8

Developing the Humanities Competencies of STEM Undergraduate Students: New Challenges for Korean Higher Education

Byung Shik Rhee

Introduction

The Humanities, long estranged from science, technology, engineering, and mathematics (STEM) education, recently have gained the spotlight in Korea. Influential in this regard was the late Steve Jobs' remark when introducing a new Apple product in 2011: "It is in Apple's DNA that technology alone is not enough—it's technology married with liberal arts, married with the humanities, that yields us the results that make our heart sing." His provocative message was a wake-up call for Korean leading business companies, universities, and the national government alike.

Although these entities might have different motivations and priorities, they apparently share the view that Korean STEM education has yet to adequately develop the humanities competencies of its students. And certainly, this common perception is not refuted by the modern history

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*,
International and Development Education,
https://doi.org/10.1007/978-3-319-98666-1_8

of STEM education in Korea. Over the past several decades, Korea has adhered to a so-called efficiency-oriented "fast follower model of educational development" that separates high school students into two tracks, liberal arts and natural science. Students in the latter track were systematically limited in their liberal arts (humanities) class options in high school. Since 1980 furthermore, national efforts have been made to establish science (and technology)-specialized high schools and universities wherein humanities and liberal arts education is even more curtailed. Granted, without this approach, it would not have been possible to meet and surpass fast-growing industries' workforce needs and expectations during Korea's rapid industrialization, nor to enable two science-and-technology-centered universities (established in the 1980s) to attain world-class status (Rhee 2011). But these achievements have been made at the cost of a more integrated, well-balanced, and holistic education.

To address this issue, the Korean Ministry of Education (MOE) recently decided to completely phase out the half-century-old dual-track liberal arts/natural science system in academic high schools. The government's multiyear subsidy program called CORE (initiative for College of humanities' Research and Education) (60 billion KRW/year) was started in 2016 to support sixteen participating higher-education institutions' curricular overhaul for development of undergraduates' humanities capabilities (MOE 2015). Notwithstanding these national initiatives, our understanding of the humanities competencies of STEM undergraduate students remains substantially incomplete. Scholarly discussion as to what constitutes those competencies and how they can be measured has only just begun; there is as yet little research on how they change during college or on what matters in the process (Song et al. 2015). This study aimed to fill that gap by examining the humanities competencies of STEM students enrolled in a top-tier science and technology university in South Korea. The research questions were as follows:

1. What are the current humanities-competency levels of STEM undergraduate students?
2. How do the humanities competencies of STEM students change by year during college?
3. What collegiate factors influence the humanities competencies of STEM students?

Key Features of Korean STEM Higher Education: Expansion and Transformation

Three major trends characterize contemporary STEM higher education in South Korea. First, the number of students enrolled in STEM majors has steadily increased over the past few decades along with a similar trend in the overall number of college students (MOE and KEDI, 1981–2016 selected years). The increase of STEM enrollment, however, has been slower than that of four-year enrollment, in part because students continued to avoid the STEM fields for various reasons, such as the difficulty of studying math and science and poor career prospects. Currently, about 800,000 students are enrolled in STEM majors in almost all of the four-year institutions of higher education, which accounts for about 40% of the total enrollment (Fig. 8.1).

Second, there has been a gradual shift in the general education of STEM majors, particularly engineering students, from the STEM-blind approach to a STEM-conscious approach (Han et al. 2016). For example, the accreditation board for engineering education mandated a new set of student learning outcomes that emphasized the generic skills relevant to STEM students, which included communication, self-directed learning, understanding of societal impacts of engineering solutions, and career ethics (ABEEK 2015). According to this new accreditation guideline, the "one-size fits all" approach to general education has gradually been changed to a more customized one that better meets the educational needs of undergraduate students in engineering programs.

Third, more recently, universities have undergone a transformation in academic structure and curriculum to meet the ever-increasing demand from stakeholders outside the university for a new, integrated approach to STEM higher education. With generous government subsidies, universities now actively seek new means of integrating formerly distant fields of studies at the institutional and course levels. In line with this trend, tightly integrated multidisciplinary courses, new schools, and departments wherein students can learn a diverse array of fields from science and technology to humanities, social sciences, art, and design have grown in popularity. Some exemplary academic units in leading universities are these: the School of Integrated Technology at Yonsei University, the College of Liberal Arts and Convergence Science at Korea Advanced Institute of Science and Technology (KAIST), Creative IT Engineering

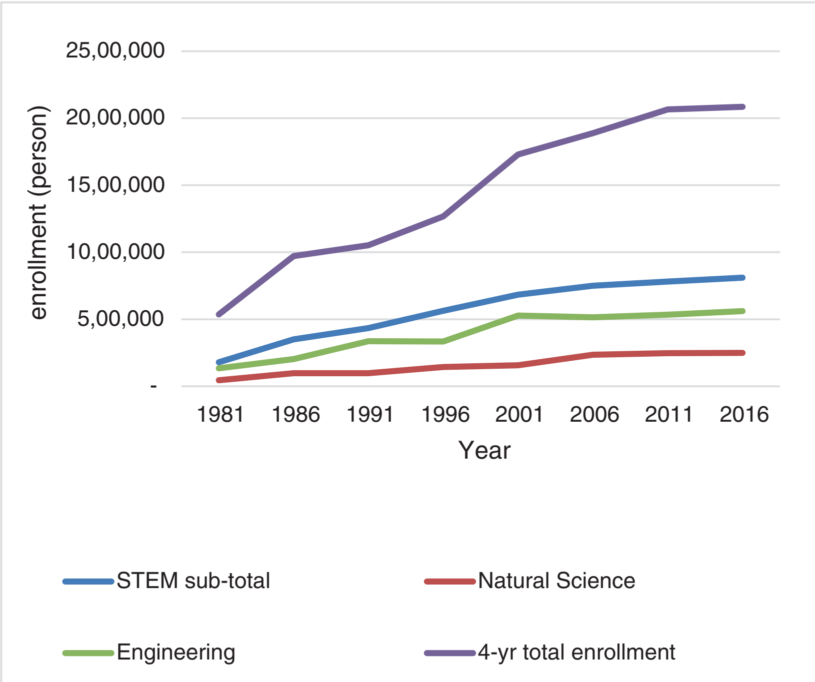


Fig. 8.1 Enrollment trends of STEM majors and 4-year college students, 1981–2016 (*Source* MOE and KEDI. *Brief Statistics on Korean Education*, selected years)

at POSTECH (Pohang University of Science and Technology), and the Graduate School of Convergence Science and Technology at Seoul National University.

What Does It Mean to Have a Good Grounding in the Humanities?

A good grounding in the humanities has been heralded in recent years as integral to success in many professions. In some fields, such as medicine, nursing, and public health, wherein professionals and practitioners interact more directly with their clients, the role of the humanities has been more widely accepted. The medical humanities, for example, started in 1970s, have complemented medical education by stressing the human side of medicine (Brody 2011). The humanities have also helped nursing students to better understand human beings, provide person-centered care, and develop critical thinking (Ha et al. 2017). Yet, in the STEM fields wherein such interpersonal interactions are rare or at least rarely anticipated, the humanities have hardly drawn any attention until recently in Korea. The aforementioned remark by Apple's ex-CEO, though, stirred Korean business enterprises. It drove corporate management and leadership in leading companies to develop first their own humanities knowledge and then that of their employees as well. They even made it publicly known that they preferred, as their new hires, STEM students having a good grounding in the humanities.

Notwithstanding the humanities' new popularity in Korea, people still have only a vague understanding of what they or their attributes or skills exactly mean, and there is as yet no agreement on what STEM students should know and be able to do in the humanities realm. Nonetheless, there are at least two dominant conceptions of what a good grounding in the humanities entails. The first is that a person with a good grounding in the humanities is one who has a decent knowledge of literature, history, and philosophy, the traditional humanities disciplines. This conception can be seen to be at work in recent hiring practices within the private sector.

The second conception of what it means to have a good grounding in the humanities encompasses the broad abilities that are the learning outcomes of liberal arts education. According to this conception, people with those abilities are not necessarily those who know more about the humanities but those who can think like those who have studied the humanities. Following this line of thought, a Korean cognitive psychologist suggested five attributes that could constitute a good grounding in the humanities for business purposes: sophistication, morality, creativity, human-centered perspective, and critical thinking (Mo 2015). This conception resonates with scholarly discussions on general education for natural science and engineering students as well as the accreditation standards of engineering education.

Considering all of these ideas together, a good grounding in the humanities can be regarded as a combination of humanities knowledge, humanistic attitudes and values, and humanities skills. These attributes are often referred to as humanities competencies.

Research Method

Data Collection and Sample[1]

Data was drawn from STEM undergraduate students enrolled in one of the leading science and technology universities in Korea. The university, established in the mid-1980s, has 12 departments with about 1500 undergraduate and 2000 graduate students. Currently, it is in the top 10 in *Times Higher Education's* Asian university rankings (*Times Higher Education* 2017). The survey was administered to undergraduate students at the university from June 11 to 18, 2014. The initial sample consisted of 852 students and the response rate was 66%. After excluding students with missing data on variables of interest and applying some restrictions, the final sample for our multivariate regression analysis numbered 665.

Measurement

To capture the multifaceted notion of humanities competencies as broadly as possible, this study used multiple measures including students' humanistic attitudes, abilities, and morality.

Students' humanistic attitudes measured were their *positive attitude toward literacy and habit of mind*. The former reflects the extents to which students enjoy activities, such as reading poetry and literature, reading scientific and historical material, and expressing ideas in writing ($\alpha = 0.75$). The latter indicates how often they engage in critical thinking ($\alpha = 0.74$). Each scale, composed of several items, was derived from surveys initially developed in the United States (for the Wabash National Longitudinal Study of Liberal Arts Education and the Cooperative Institutional Research Program) and then adapted to Korean students. Humanities ability was measured on the 10-item *creativity* scale developed by a group of psychologists at Yonsei University ($\alpha = 0.81$). Morality was measured using an abbreviated version of the personality instrument developed by Lee and colleagues (2013); it consists of two

[1] This study used data collected for the author's earlier research project (2014) funded by the POSCO Research Institute.

dimensions, namely the cognitive and affective aspects of morality. In our study, only *cognitive morality*, comprehending moral self-recognition, appreciation of moral values, moral reasoning, and reflective decision-making was examined ($\alpha = 0.81$).

In order to explore the factors associated with the humanities competencies of STEM students, several composite scales, such as *faculty mentoring*, *student cognitive engagement*, and *supportive institutional climate* scales also were developed. Their items were borrowed from the questionnaire developed by the UCLA Higher Education Research Institute and subsequently adapted by the Yonsei University Global Higher Education Research Center.

Analyses

To determine the levels of students' humanities competencies, simple descriptive statistics were computed for each domain. ANOVA was used to determine if there were any mean year-to-year differences in humanities attitudes, ability, or morality. When a statistically significant difference among students by year was identified, further analysis was conducted by post hoc tests. Multivariate regression analysis was performed to explore the factors influencing students' humanities competencies. Multicollinearity was examined by the variance inflation factor (VIF) for all of the independent variables in the model, each of which was smaller than 3.0. Exploratory factor analysis and internal consistency analysis were applied to determine the validity and reliability of the summated scales. For convenience of interpretation, all of the summated scales were transformed to retain their original units.

Findings

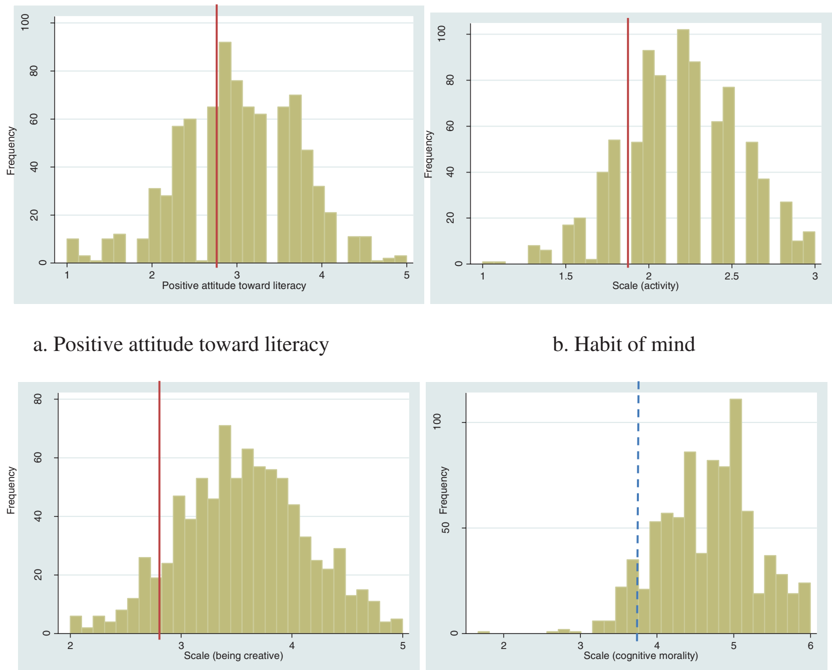
Current Humanities-Competency Levels of STEM Students

Table 8.1 and Fig. 8.2 show the current levels of humanities competency as measured by the following four components: students' attitudes toward literacy, habit of mind, creativity, and morality. Overall, as the means (slightly over the center point on each scale) suggest, students' humanities competencies were moderate. Specifically, only

Table 8.1 Humanities competencies (no. of students = 846)

Components	*Mean*	*Std. Dev.*	*Range: low to high (center point)*
Positive attitude toward literacy	3.02	(.71)	1–5 (3)
Habit of mind (critical thinking)	2.19	(.35)	1–3 (2)
Creativity	3.56	(.55)	1–5 (3)
Cognitive morality	4.66	(.63)	1–6 (4)[a]

[a]For morality, the center point (4) refers to the minimum point at which a student can be considered to be a moral thinker



a. Positive attitude toward literacy

b. Habit of mind

c. Creativity

d. Cognitive morality

Fig. 8.2 Histograms of STEM student's humanities-competency levels for positive attitude toward literacy, habit of mind, creativity, and cognitive morality (The solid vertical (red) line in the graphs indicates the center point of each scale, and the dotted (blue) line the minimum point at which a student can be considered to be a moral thinker) one in ten students said that they enjoyed reading and writing in the humanities, and just one in four considered themselves to be creative.[2] One in three students was certain that they were a moral thinker.[3] Yet a majority of students, three of four, said that they often engaged in critical thinking.[4]

Change of Humanities Competencies by Year

Comparing the mean of each underlying component by year revealed that the humanities competencies changed in an intriguing way over time. These yearly change patterns appeared to roughly follow a *U*-shape. As in Fig. 8.3, across all categories, competencies continued to drop until the third year, were recovered in later years, but failed, in most cases, to rise beyond their initial level. The dotted straight lines with a negative slope also affirm that all but *habit of mind* declined trend-wise during the years. Notwithstanding, from a more strictly statistical point of view, a significant difference existed only in certain years: between freshmen and juniors on all but *habit of mind*, and between second- and third-year students and seniors on *habit of mind*. Taken together, it is evident that the humanities competencies steadily declined over the years to a certain point, in our case, during the third-year, and that overall, no significant change emerged with respect to the difference between entering and graduating students.

Factors Associated with Humanities Competencies

To explore the collegiate influences on the humanities competencies of STEM students, this study performed multivariate regression and multivariate hypothesis testing. The results, as indicated in Tables 8.2 and 8.3, affirmed that humanities competencies did decline over time during college ($F_{(4,\ 648)} = 6.67$, $p < .001$) and that engineering students perceived their humanities competencies to be weaker than those of natural science students ($F_{(4,\ 648)} = 3.65$, $p < .05$), even controlling

[2] Those who responded with 4 or more out of 5 on each of “positive attitude toward literacy” and “creativity” were counted.

[3] Students who responded with 5 or more out of 6 on “morality” were counted.

[4] Those who responded with 2 or more out of 3 on “habit of mind” were counted.

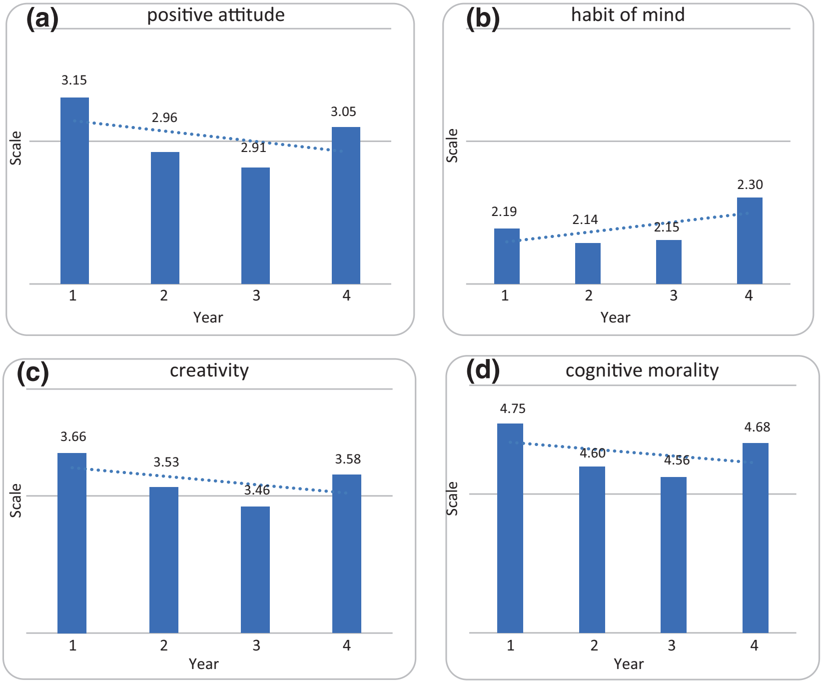


Fig. 8.3 STEM students' yearly change as measured in means for positive attitude toward literacy, habit of mind, creativity, and morality ($n = 705$).
Note: 1, 2, 3, and 4 on the horizonal line (Year) indicating freshman, sophomore, junior, and senior year, respectively on all figures (a), (b), (c), (d)

for the student personal and family background, and the type of high school they attended. Among the other collegiate factors, faculty mentoring ($F_{(4,\ 648)} = 7.75$, $p < .001$), student engagement ($F_{(4,\ 648)} = 29.9$, $p < .001$), and supportive institutional climate ($F_{(4,\ 648)} = 5.65$, $p < .001$) turned out to be significant, whereas the number of liberal arts courses taken failed to remain significant across the dependent variables after the independent variables were taken into account. Basically, it can be concluded that humanities competencies can be enhanced as students are given appropriate faculty mentorship, engage in active and/or collaborative learning, and feel more supported in and out of class. However, taking additional liberal arts courses would not necessarily guarantee enhancement.

Table 8.2 Multivariate regression results for positive attitude toward literacy and habit of mind

		Coeff. (s.e.)	*t*
Positive attitude toward literacy ($R^2 = 0.15$)			
Personal background	Female	−0.062 (.065)	−0.96
	Income[1] (2–4 m/month)	−0.131 (.090)	−1.44
	Income[1] (4–6 m)	−0.079 (.092)	−0.86
	Income[1] (6–10 m)	0.016 (.100)	0.16
	Income[1] (10 m or more)	0.034 (.131)	0.26
	First-generation college student	0.150 (.065)	2.30*
	Military service (no)	−0.082 (.114)	−0.72
High school characteristics	Special-purpose high school[2]	−0.130 (.063)	−2.06*
	High school location[3] (capital area)	0.002 (.067)	0.03
	High school location[3] (major city)	0.013 (.069)	0.18
College experiences	Year (grade)	−0.102 (.034)	−2.99**
	Major: Engineering[4]	−0.144 (.057)	−2.52*
	No. HSS courses taken	0.070 (.032)	2.18*
	Faculty mentoring (scale)	0.253 (.065)	3.88***
	Cognitive engagement (scale)	0.558 (.109)	5.13***
	Supportive institutional climate (scale)	0.102 (.091)	1.13
	_constant	1.674 (.365)	4.59
Habit of mind (critical thinking) ($R^2 = 0.34$)			
Personal background	Female	−0.030 (.029)	−1.03
	Income[1] (2–4 m/month)	−0.007 (.040)	−0.17
	Income[1] (4–6 m)	0.025 (.041)	0.62
	Income[1] (6–10 m)	0.045 (.044)	1.01
	Income[1] (10 m or more)	0.091 (.058)	1.57
	First-generation college student	−0.005 (.029)	−0.17
	Military service (no)	0.112 (.050)	2.24*
High school characteristics	Special-purpose high school[2]	0.025 (.029)	0.92
	High school location[3] (capital area)	0.032 (.029)	1.09
	High school location[3] (major city)	0.026 (.031)	0.84
College experiences	Year (grade)	0.022 (.015)	1.43
	Major: Engineering[4]	−0.082 (.025)	−3.27**
	No. HSS courses taken	0.009 (.014)	0.62
	Faculty mentoring (scale)	0.138 (.029)	4.81***
	Cognitive engagement (scale)	0.480 (.048)	10.01***
	Supportive institutional climate (scale)	0.143 (.040)	3.58**
	_constant	0.345 (.161)	2.15

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Note The reference groups of the superscripted numbers are as follows: 1 = income below 2 million KRW, 2 = academic high school, 3 = local area, 4 = natural sciences

Table 8.3 Multivariate regression results for creativity and cognitive morality ($n = 665$)

		Coeff. (s.e.)	*t*
Creativity ($R^2 = 0.18$)			
Personal background	Female	−0.033 (.049)	−0.67
	Income[1] (2–4 m/month)	−0.027 (.069)	−0.39
	Income[1] (4–6 m)	0.018 (.070)	0.25
	Income[1] (6–10 m)	0.020 (.076)	0.27
	Income[1] (10 m or more)	0.140 (.100)	1.41
	First-generation college student	0.063 (.049)	1.28
	Military service (no)	−0.097 (.086)	−1.12
High school characteristics	Special-purpose high school[2]	−0.011 (.048)	−0.23
	High school location[3] (capital area)	0.046 (.051)	0.92
	High school location[3] (major city)	0.019 (.053)	0.36
College experiences	Year (grade)	−0.091 (.026)	−3.49**
	Major: Engineering[4]	−0.064 (.043)	−1.47
	No. HSS courses taken	0.053 (.024)	2.19*
	Faculty mentoring (scale)	0.107 (.050)	2.15*
	Cognitive engagement (scale)	0.600 (.083)	7.25***
	Supportive institutional climate (scale)	0.137 (.069)	1.99*
	_constant	2.094 (.277)	7.55
Cognitive morality ($R^2 = 0.16$)			
Personal background	Female	0.223 (.055)	4.04***
	Income[1] (2–4 m/month)	0.004 (.077)	0.05
	Income[1] (4–6 m)	0.019 (.078)	0.24
	Income[1] (6–10 m)	0.032 (.085)	0.38
	Income[1] (10 m or more)	0.248 (.111)	2.23*
	First-generation college student	0.015 (.055)	0.26
	Military service (no)	−0.007 (.096)	−0.07
High school characteristics	Special-purpose high school[2]	0.021 (.053)	0.39
	High school location[3] (capital area)	0.022 (.056)	0.39
	High school location[3] (major city)	0.057 (.059)	0.96
College experiences	Year (grade)	−0.035 (.029)	−1.22
	Major: Engineering[4]	−0.086 (.048)	−1.78
	No. HSS courses taken	0.012 (.027)	0.45
	Faculty mentoring (scale)	0.104 (.055)	1.88
	Cognitive engagement (scale)	0.414 (.092)	4.48***
	Supportive institutional climate (scale)	0.290 (.077)	3.78***
	_constant	2.697 (.309)	8.72

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Note The reference groups of the superscripted numbers are as follows: 1 = academic high school, 2 = income below 2 million KRW, 3 = local area, 4 = natural sciences

Conclusion

The major finding of this study is somewhat disappointing in that the humanities competencies of STEM students were not as high as we would have expected from students in one of the most prestigious and resourceful universities in Korea. The clear implication is that the students felt themselves to be lacking in humanities competencies and that they had much room for growth. Nevertheless, we cannot yet say with confidence that their humanities competencies were truly deficient, as our study relied mainly on students' self-reported attitudes and abilities. Our finding, however, seemingly accords with the public perception of the "weak" humanities competencies of STEM students as well as the necessity for more extensive integration of humanities into STEM education.

More importantly, this study found no discernable enhancement in the humanities competencies of STEM students, and even worse, a slight decline in some measures over the course of their enrollment. Although these findings surely are undesirable, the same pattern has been noted in the United States. The Wabash National Longitudinal Study of Liberal Arts Education, having surveyed over 17,000 students from 49 colleges and universities, documented a decline in the attitude toward literacy over time, with a slight increase in critical thinking and moral reasoning abilities (Blaich and Wise 2011). Surely, more research is required to ensure that this pattern can survive more methodologically rigorous tests[5] and hold true for other institutions in Korea. Nevertheless, these findings suggest that humanities competencies might take a longer time to develop and, also, that the educational environment necessary for their development might not yet be adequate.

Finally, our data clearly shows that STEM students can develop humanities competencies by improving their college experiences. To this end, not only students themselves but also faculty members and universities as a whole should play a more active role. In the meantime, an increasing number of colleges and universities have already begun to undergo a massive transformation in general education. Yet, many challenges to the enlargement of the humanities component within STEM higher education await. Evidently, our recent STEM students require

[5] It can be argued that this pattern would not have held if longitudinal data had been used or if students had been rigorously matched.

remedial education in STEM basics as a result of the fast expansion and a more relaxed requirement for college admission (Hong et al. 2013). Curriculum wise, as increasing numbers of the most talented graduate students leave Korea to study abroad, professors in STEM departments have had to select undergraduates as their research and lab assistants, and concomitantly, they have felt obliged to intensify the core STEM component of their undergraduate programs (Shin et al. 2011). Moreover, at the classroom level, leading universities, in order to keep up with the pace of internationalization, increasingly require professors to teach—and students to take—STEM courses in English (Byun et al. 2011). All of these factors would tend to complicate efforts to make the humanities a larger part of STEM higher education.

References

Accreditation Board for Engineering Education in Korea. 2015. *Accreditation Standards for Engineering Education. ABEEK-2014-ABE-010.* Seoul, Korea: Accreditation Board for Engineering Education in Korea.

Blaich, Charles, and Kathleen Wise. 2011. *From Gathering to Using Assessment Results: Lessons from the Wabash National Study.* Champaign, IL: National Institute for Learning Outcomes Assessment.

Brody, Howard. 2011. "Defining the Medical Humanities: Three Conceptions and Three Narratives." *Journal of Medical Humanities* 32: 1–7.

Byun, Ki Yong, Huijung Chu, Minjung Kimm, Innwoo Park, Suhong Kim, and Juyoung Jung. 2011. "English-Medium Teaching in Korean Higher Education: Policy Debates and Reality." *Higher Education* 62: 431–449.

Ha, Ju-Young, So-Young Jeon, and Ji-Won Cheon. 2017. "Concept Analysis of Humanities Knowledge: Nursing Application." *Asia-Pacific Journal of Multimedia Services Convergent with Art, Humanities, and Sociology* 7 (1): 937–947.

Han, Kyonghee, Dong-Hyun Ko, and Moonhee Choi. 2016. "Direction for the Reform of Liberal Education in Engineering in an Era of Convergence." *Journal of Engineering Education Research* 19 (2): 14–25.

Hong, Sungmin, Hyungju Kim, Kawon Cho, Kibum Park, and Sunwoo Kim. 2013. *Future Science and Engineering Talents.* STEPI Insight no. 131. Sejong-si: Science & Technology Policy Institute.

Lee, Yoon-Sun, Hye-Young Kang, and So-Jung Kim. 2013. "A Validation Study of Character Index Instrument for College Students." *Journal of Ethics Education Studies* 31: 261–282.

Ministry of Education, 2015. "CORE (Initiative for College of Humanities' Research and Education) Basic Plan." Seoul, Korea: Ministry of Education.

Ministry of Education and Korean Educational Development Institute. 1981–2016. *Brief Statistics on Korean Education*. Selected Years. Seoul, Korea: MOE & KEDI.

Mo, Kiryong. 2015. *Why Do Leading Companies Pay Attention to the Humanities?* Seoul: Dasanbooks.

Rhee, Byung Shik. 2011. "A World-Class Research On the Periphery: The Pohang University of Science and Technology, the Republic of Korea." In *The Road to Academic Excellence: The Making of World-Class Research Universities*, edited by Philip Altbach and Jamil Salmi (pp. 101–127). Washington, DC: The World Bank.

Rhee, Byung Shik. 2014. "Humanities Competencies Assessment of POSTECH Undergraduate Students." Seoul, Korea: Research Center for Global Higher Education, Yonsei University.

Shin, JungCheol, SaeJung Youn, JiSun Jung, SoYeon Lee, and HyeJoo Jung. 2011. "Structural Characteristics of Undergraduate Subject Major Curriculum in Korea." *Asian Journal of Education* 12 (1): 69–91.

Song, Hyojin, Dongjoo Sinn, and Choongjin Song. 2015. "Does an Accredited Engineering Program Contribute for Training the Creative Talented Engineers? Based on Students' Experiences and Learning Performance." *Journal of Governance Studies* 10 (2): 95–116.

Times Higher Education. (2017). "Asia University Rankings 2017." https://www.timeshighereducation.com/world-university-rankings/2017/regional-ranking#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats.

CHAPTER 9

Cultivating Students' Diverse Abilities Through Arts Education: Emergence of the STEAM Perspective

Yi Yang

Introduction

Li Zhengdao, a Chinese-American Nobel-prize winner in physics, once said: "Science and art are two sides of the same coin." It is well known that science and art have played an equally important role in the development of human history. In ancient times, art and science were naturally integrated, whereas in the Middle ages, science gradually separated from art as it came to be studied in discrete disciplines, such as mathematics, natural sciences, and ethics. Subsequently, in modern times, with the subdivision of science and its dramatic influence on human life, science has been decoupled from art totally. However, compared to art, the significance of science seems to have caused more concern. This trend can be observed in most countries. Over the past one hundred years, in order to increase national competitiveness, many countries have been paying

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*,
International and Development Education,
https://doi.org/10.1007/978-3-319-98666-1_9

more attention to building up the fields of science and technology. China is no exception. From the 1950s, strengthening science and technology became the core policy of Chinese education and nation-building. As a result, China is now economically competitive and even surpassing most of the western countries in the world. But this over-emphasis on science has led to a neglect of the study of arts, and there exists a tendency to generally undervalue the arts and regard them as unimportant.

Fortunately, some educators and enterprise leaders do not think the arts should be consistently denigrated in a science-oriented society; rather, they believe that the arts can help develop science and technology. As John Lasseter has said, “Technology inspires art, and art challenges the technology.” Nowadays, people prefer products that are both practical and well-designed. Practical function is not the only standard for customers to choose goods. Such as Steve Jobs, he considered both practical and well-designed in his iPhone production. At the same time, science also needs innovation. Researchers have proved that abilities, such as creativity, imagination, initiation, and critical reflection, which are required in the process of science, can be cultivated through the arts. Moreover, we are living in an information age where most of the information is transmitted through visual media, all of which involve the arts. For these reasons, people have come to rethink the essential role of Arts Education as they realize its value for both individual growth and social development.

Changes in the tension between science and the arts are already happening, and the two acronyms STEM and STEAM reflect the shift in thinking. As many educators and business leaders mentioned below, if the former refers to the power and value of science, the latter represents an attitude and re-recognition toward the arts. Giving consideration to Arts Education can be seen not only as a reflection of the past, but also a way forward.

However, when thinking about Arts Education, there is much debate concerning its curriculum and its many possible aims. As UNESCO mentioned in its document, “Road Map for Arts Education,” the debate leads to questions such as: “Is arts education taught for appreciation alone or should it be seen as a means to enhance learning in other subjects?” “Is art education for a gifted few in selected disciplines or is art education for all?” (UNESCO 2006). These debates continue, and they often become the focus of each Arts Education conference.

This chapter introduces the Chinese Arts Education movement for the twenty-first century. Analyzing the method of teaching visual arts in primary school will clarify the changes in Arts Education. The chapter consists of four sections. The first section offers a brief description of what caused the transition from STEM to STEAM. The second section shows the trends and issues in the current Chinese STEAM research. The third outlines the role of Arts Education in promoting educational reform. And finally, an example will be shown to demonstrate the features of the visual arts in a primary school.

From STEM to STEAM: Why the "Arts" Is Necessary

Since the 1980s, the United States has recognized that the decline of science and technology would bring about a shortage of human resources. In order to maintain global leadership and national sustainable global competitiveness, they promoted an educational curriculum which focused heavily on the four STEM areas. STEM was first promoted by UNESCO in the 1980s. Over the past 30 years, the US government has been continuously promoting the development of STEM in various ways, such as through legislation, providing funding and encouraging special projects.

Former President, Barack Obama, was a positive proponent of STEM, and from early in his Administration made the improvement of STEM education a priority. He believed that every American student deserved access to a high-quality education in STEM. He and others argued that the United States must remain innovative and technologically savvy, and this is predicated on the prevalence of STEM-literate workers (Swaby and Ernst 2016, p. 18), Obama's PCAST (The President's Council of Advisors on Science and Technology) report entitled, "Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics," states: "economic projections point to a need for approximately 1 million more STEM professionals than the U.S. will produce at the current tat over the next decade" (PCAST 2012). This report suggests that more students must be engaged to excel in STEM.

However, this science-based education ideal has raised widespread questions in the field of the arts. Some artists and educators think that STEM education seems to ignore the fact that, in addition to advanced science and technology, the success of industry and the economy depends largely on creativity, aesthetic sensitivity, and originality, which are essential components of its success. They suggest that the current emphasis on STEM education should expand to include an equal emphasis on art and design. Harvey White, founder of Qualcomm Inc., advocated that "STEAM" should replace "STEM." He writes, "A STEAM-based education system gives a country an advantage, or at least a level playing field, in the innovation race. We need to equip our technologists and leaders with the best training possible and add arts to STEM and put STEAM to work" (*The San Diego Union-Tribune* 2010). His perspective was adopted by artists and educators reinforcing the value of the role of Arts Education and its importance for the future of America.

Under the advocacy of these supporters, the President's Committee on The Arts and Humanities released a report at the Art Education Conference in 2011, called "Reinvesting in Arts Education: Winning America's Future Through Creative Schools." It states that "to succeed today and in the future, America's children will need to be inventive, resourceful, and imaginative. The best way to foster that creativity is through arts education" (PCAH 2011). This report also provides evidence of the important connection between art and culture, creativity and innovation, and the urgent need for a new agenda for reinventing education in America.

The significance of arts began to be proven through academic investigations. Some research results have proved that students who study the arts in high school achieve higher SAT scores than those who do not study the arts (Vaughn and Winner 2000, p. 86). The College Board shows that students who take 4 years of arts and music classes while in high school on average score about 100 points better on their SATs than students who take only half a year or less (College-Bound Seniors 2011).

Georgette Yakman, a founder of the STEAM education idea, points out that S-T-E-M with an "A" added the following four factors: (1) sharing knowledge with language arts, (2) a working knowledge of manual and physical arts, (3) a better understanding of the past and present through fine arts, and (4) understanding development with social/liberal arts perspectives. In her view, "A" combines knowledge in various fields, such as sociology, psychology, history, politics, and philosophy. As an abstract symbol with wide-ranging meanings, "A" does not have a precise definition, but STEAM-learning encompassed all the essential components of the mind, heart, body, and spirit which are more closely aligned with the students' real life, making their studies more attractive.

STEAM Research in China

The commonalities, as well as the differences between STEM and the arts in terms of the skills required in the learning process, are examined. Even when people use the same word to describe skills in both areas, the way of thinking is different. For example, problem-solving is a skill necessary in both, but in STEM people use concepts, laws, estimations, and approximations, to measure the accuracy of calculations. In the arts, people turn to aesthetics, imagination, creativity, and cooperation. On the other hand, both science and the arts interact as they aim at pursuing truth and beauty (Chen 2015, pp. 51–52). The interactive relation is usually regarded as an effective way in the learning process; for instance, using the arts can encourage children to love mathematics and science. And there is no doubt that curiosity, enthusiasm, strong will, and a challenging spirit are helpful for science innovation.

Humanities, as well as the arts, are beneficial to scientific thinking. As is mentioned in "A Nation at Risk,": "Knowledge of the humanities… must be harnessed to science and technology if the latter are to remain creative and humane, just as the humanities need to be informed by science and technology if they are to remain relevant to the human condition" (1983, pp. 10–11). Science, arts, and humanities are indispensable to the full development of the individual. Based on this ideal, integrating science, arts, and humanities competencies is regarded as most countries' educational general goals.

In 2014, the Chinese Ministry of Education proposed "To Develop the Chinese Students' Core Competencies," indicating that core competencies would be the essential characteristics and main abilities for life-long study and social development. Core Competency is a learner-centered concept and can be classified into three aspects: basic knowledge, individual development, and social participation. Basic knowledge can, therefore, be understood as the integration of humanities, arts, and science. Literacy in the humanities requires humanistic knowledge, humanistic methodology, human-oriented ideal, respect for human dignity and values, as well as for individuals' lives and well-being. On the other hand, aesthetic study equips learners with skills, such as aesthetic awareness, aesthetic appreciation, critical evaluation, and understanding cultural and artistic diversity, which enables them to express themselves in an artistic way, and to expand and sublimate their subjective ability in the world. Scientific literacy requires students thinking rationally and critically with a challenging spirit.

Nowadays, to acquire knowledge does not merely mean to study one subject—one needs to build one's own body of knowledge to understand it better. Knowledge of natural sciences might help you to understand the birth of a historical event; a work of literature might give you some ability to discover the mysteries of science. STEAM, which aims at integrating science and art, emphasizes the collaborative reflection between the two and can be considered as the most effective way to develop the students' core competencies needed in a creative society.

Chinese STEAM research started in 2007. Apart from the publication of several translated books, it had little impact in the first few years. It has been highlighted since 2014 due to the Chinese government's advocating the importance of innovation in the development of economics, followed by the government putting forward "The Thirteenth Five-years planning of Educational Information," pledging to incorporate STEAM into education. The Department of Education Information Center and Beijing Normal University published the "Chinese STEAM Education Report" in 2017. This report gave us a glimpse into current STEAM research status and problems.

The survey illustrated that lack of government policy and financial support, an unclear definition of the concept of STEAM, an incompletely integrated STEAM curriculum, and shortage of professional teachers are the main reasons why STEAM is not being widely implemented in schools. In terms of curriculum, 35% of schools provide one lesson per week; 57% provide two lessons, and only 4% provide three. Even though these schools provide STEAM, over 50% of them incorporate it in social activities, instead of offering it as formal lessons. As for teaching material, 60% of what the teachers use is provided by other educational institutions. These teaching materials mostly focus on the information or technology curriculum requirements, lacking the perspective to consider the integration of science, mathematics, and the arts. Furthermore, teaching method such as inquiry-based (68.7%) and cooperative learning (60.4%) are essential to STEAM learning and are the most common methodology of the teachers. On the other hand, project-based learning, problem-solving learning, and design-based learning, which place value on STEAM, are seldom adopted. STEAM education requires qualified teachers with both STEM literacy and artistic literacy, but most teachers engaged in STEAM have only a STEM background, lacking artistic literacy and thus limiting their ability to teach the arts (Report 2017, 83–89).

As a direction for future education, STEAM will become the main trend and make more changes to our school education. To define STEAM, we should first look at the crucial role played by the arts. Aesthetic and artistic awareness can be cultivated through Art Education. The movement of and research in Arts Education in recent years may provide the perspective for which to think of STEAM.

General Goal of Arts Education Since 2000

Arts Education has a long history and cultural tradition in China. Each Chinese character had a deep, profound meaning when it is created. The term of art is composed of two characters *yishu* (藝術). *Yi* (藝) means to plant, grow, cultivate, and as a noun it means a kind of skill or technique, and *shu* (術) shows path, way, or method as a noun, and as a verb, it means to gain a skill or acquire a method. As can be seen, the original meaning of art differs from how people understand it today.

The emphasis on the influence of the arts on an individual's development is derived from Confucian philosophy. In ancient times, students who wanted to become scholar-officials were required to learn six classical subjects. Confucius was interested above all in the moral perfectibility of mankind. He laid great emphasis on his ideal of rites and arts. Therefore, his views have had far-reaching consequences for the Chinese attitude toward arts education.

After the foundation of the new China in 1949, the process toward Arts Education comprised four phases. The first, from the 1950s to the mid-1960s, was the establishment phase. Then, from the end of the 1960s to the late 1970s was the stagnant phase, due to the Cultural Revolution. During that decade, only *Yang Pan-xi* (樣板戲, a kind of Revolution Art) was permitted to be performed. After that, with the economic reform of the mid-1980s, the recognition of the arts became a concern in academic circles and many western esthetics and art theories were introduced to China.

Since 2000, the government has proposed a series of policies to promote the dissemination of Arts Education. "The Opinion on Strengthening and Improving School Overall Aesthetic Education" (2015) was issued by China's State Council. In this document, the government outlined many specific requirements for arts education.

Their aim was to strengthen and improve school esthetic education from 2015, and, by 2018, for there to be a breakthrough achievement, an optimization of resource distribution, and further improvement in the management mechanism, such that all kinds of schools at all levels could apply for arts courses. By 2020, their aim is the collaboration between kindergartens, primary schools, middle schools, high schools, and universities, with an interaction of activities in and out of schools, cooperative relations between arts literacy and professional education, and a wider cooperation between schools, families, and society. Currently, problems concerning disparities among regions have a serious impact on education. The conditions in different geographical areas not being uniform, the purpose of the government is to provide arts education for all and thereby achieve the popularization of arts education throughout the country.

Current Changes of Visual Art

For the visual arts, five desired competencies were specified in 2016. These were: (1) image recognition, (2) expression through artistic means, (3) aesthetic judgment, (4) creativity, and (5) cultural understanding. Nowadays, research looks at all levels of education—junior, middle, high school, and university. Although many people think that arts education is a long-term and continuous process, it is more important to start students thinking about what the arts are during their primary education. The sooner they gain more artistic experience, the deeper their insights and understanding of the arts will be. East Beijing Road Primary School is a top-class school in Nanjing, Jiangsu Province. It has more than 1300 pupils and 130 teachers. Over more than 20 years, the school has constantly placed emphasis on arts education. The art teachers organize their own teaching plan according to the students' interests and level.

In this primary school, teachers are using a unique way to teach visual arts. The name of this technique is "Tell us your story about the arts." Therefore, in adding to practical skills learning, storytelling is used in the teaching process. The pupils can choose any topic they like to tell their story about the arts in 5 or 10 minutes. By telling their story, the teacher can get a grasp of their understanding of the arts that this can make their teaching more effective. By studying videos and recordings from three classes and interviewing the teachers, some characteristics of their arts teaching approach emerged. Table 9.1 shows the topics and contents

Table 9.1 Category of title and content

No	*Category*			*Class One (29)*	*Class Five (29)*	*Class Six (30)*
1	Artists and their works	Chinese	Ancient	4	5	5
			Modern	5	5	3
		Western	Ancient	1	2	2
			Modern	7	7	7
2	Introduction of famous works			4	2	8
3	Schools of art			2		1
4	Literary works, fairy tale			2	5	1
5	Animals					1
6	Landscape painting			1	1	
7	Museum			1	1	
8	Sculpture			2	1	1
9	Cartoon					1

Source Created by the author and based on the Grade 3 curriculum they chose. The arts can be classified into nine categories (see Table 9.1). Even though the teacher gives them no limitations, these categories cover most of the arts. Pupils prefer to know the arts from the artists and their works are good at finding some elements from traditional stories, and they love literacy works and fairy tales as well. However, even if they have been watching too many cartoons, it seems that they are not as interested in animations as might be expected.

Here are two examples of their story contents

Story 1 (Class Five, Grade 3): the child talked about Anthony Browne, a famous British writer and illustrator of children's literature, and his work "Willy's Stories," in which the hero, Willy, is a gorilla. While describing some pictures in this book, she noted that Anthony's creative inspiration comes from classical works, and his work features classical conceptual features. She took some works of Georges Seurat, Vincent Willem van Gogh, Raffaello Santi, Leonardo Da Vinci, making a comparison with those of Browne's. She also mentioned the relationship between humans and animals, and that humans could be treated as pets if conditions changed. To her, the arts might well mean observe, study, and recreate.

Story 2 (Class Six, Grade 3): this child gave us some different expressive ways of describing a cat. The times and artists she mentioned; Greek, Da Vinci, Pierre-Auguste Renoir, Picasso, Andy Warhol, represent different painting styles from different periods. She used comparisons to show differences between East and West, and has noticed the impact of emotion on their works. To her, historical background, cultural understanding, and personal emotions are the essential elements for understanding the arts.

From what they say, we can also get a better understanding of their concepts of the arts. We can divide children's concept of art into the following four categories. First, it can be described by artists or their works. Second, the art forms (color, shape, line, composition, etc.) and historical background. Third, artists' personality, the way they express their ideas. And fourth, artists, time background, forms, and the onlookers' interpretation. Even if they choose the same artist or the same work, the way they interpret them are different. For example, when they talked about Leonardo Da Vinci, one emphasized his famous works, while the other illustrated his impact on the Renaissance. As can be seen, the visual arts have interdisciplinary features while maintaining the function of its own discipline.

The purpose of the class is to build up a primary understanding or a simple concept of the arts by the pupils themselves. Giving a definition of the arts is not easy, but if you have no opportunity to think about it in your own way, visual art becomes just a subject and makes no sense to you. Usually, adults have some common stereotypes when they are talking about the arts. They may be accurate but are always lacking in new ideas. Such common stereotyped views restrict our creativity. For young children, in particular, thinking for themselves is better than being taught passively. In this class, pupils have the opportunity to learn what they want to know and build their skills and knowledge in a form that can be as mesmerizing as it is worth exploring. Creative thinking, interpretation, communication are valuable skills in all fields. And these skills that developed in Arts Education enable a better understanding of STEM fields study. But how these skills affect STEM still needs further research.

Conclusion

Currently in China, teachers have more freedom to design teaching programs. Compared with the traditional teaching method of other subjects, teaching visual arts does not simply teach students how to draw and imitate. It also includes teaching ideal and methodology, from focusing on skill mastery to the cultivation of comprehensive ability, such as teaching children how to observe, interpret, reconstruct, and think critically. It has also changed from the perspective of regarding the visual arts as merely a single discipline to seeing it as the path to knowing the world of art and further thinking about the meaning of the arts in people's lives. Results are no longer considered as important as facilitating a learning-based approach. The teaching and learning ideals that give no priority to knowledge-based methods bring a diversity of evaluation.

Thus, the arts education reform, as it was initiated in China, has increased the awareness of the arts, and occasioned a rethinking of the real significance and role played by the arts in individual and social development. Nevertheless, educators are still facing many problems.

The first is we need evaluation standards to demonstrate how Arts Education impact STEM. Without evaluation standards that can be visualized and understandable, how would people interpret the meaning of arts study? How should teachers tell schools and parents that arts are as important as STEM study or even benefit to STEM understanding?

Another issue is how to narrow the gap between urban and rural areas. In urban areas, abundant educational resources and cultural facilities provide more opportunities for students. They have more artistic experience in both formal and non-formal educational settings. For example, the primary school I visited has more than 20 activity clubs. Children can choose whichever club they like to participate in. Parents in urban areas also give their children more chance to study the arts. A survey shows that more than 60% of parents (in Beijing 62%, in Shanghai 98%) send their children to various classes to obtain further arts training. In many cities, they have a lot of cultural facilities, such as museums, concerts halls, galleries, libraries, art centers, children's palace to foster children's artistic experience. However, in rural areas, the implementation of Arts Education is facing more problems.

Despite the problems and obstacles that currently exist in China, as a means of cultivating students' diverse abilities, STEAM or art education will continue. However, being merely a means is not enough; STEAM should be considered as the purpose of education itself. A means just tells students how to do a certain thing, but the purpose reminds students of why they do it. STEAM for all is an epoch-making ideal; if every student, every teacher, and every policymaker is to benefit, there needs to be patience and effort.

References

Chen Yi-qian. 2015. "Integration and Implementation: The Reform of Art Edcution in the Technological Era."

China' State Council. 2014. "To Develop the Chinese Students' Core Competencies." http://www.gov.cn.

China' State Council. 2015. "The Opinion on Strengthening and Improving School Overall Aesthetic Education." http://www.gov.cn.

College Board. 2011. "College-Bound Seniors." https://research.collegeboard.org.

Department of Education Information Center, and Beijing Normal University. 2017. *Chinese STEAM Education Report*. Beijing: China.

President's Council of Advisors on Science and Technology. 2012. "Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics." https://obamawhitehouse.archives.gov.

Swaby, Keri, and Jeremy V. Ernst. 2016. "STEM Education Fiscal Year 2015: An Analysis of Educational Investments and Expectations." *Journal of STEM Teacher Education* 51 (1): 17–31.

The President's Committee on the Arts and the Humanities. 2011. "Reinvesting in Arts Education: Winning America's Future Through Creative Schools." http://www.pcah.gov.

UNESCO. 2006. *Road Map for Arts Education*. Paris: UNESCO.

U.S. National Commission on Excellence in Education. 1983. *A Nation at Risk: The Imperative for Educational Reform*. A Report to the Nation and the Secretary of Education, U.S. Department of Education. Washington, DC: Government Printing Office.

Vaughn, Kathryn, and Ellen Winner. 2000. "SAT Scores of Students Who Study the Arts: What We Can and Cannot Conclude About the Association." *Journal of Aesthetic Education* 34 (3/4): 77–89.

Wei, Tian-yu, ed. 2015. *Creative Arts Education in Big Data Era: The Fifth World Arts Education Report (1)* 49–53. China: East China Normal University.

Yakman, Georgette. 2010. "What is the Point of STEAM? A Brief Overview of STEAM Education." August 7. http://www.academia.edu.

CHAPTER 10

STEM Education in a Changing Society: Japanese Experience and Urgent Problems to Be Solved

Masaaki Ogasawara

STEM can be translated into Japanese as the *Rikei* or *Rikoukei* field, though the Japanese term is more comprehensive and refers to a wide range of academic disciplines comprised of the natural sciences, mathematics, technology, engineering, and even agriculture and fishery. Throughout the history of higher education in Japan, in terms of the modern system, the government has continuously paid special attention to the *Rikei* field. It has been considered a key function of universities, especially those of the public sector, to produce graduates with technical and scientific abilities to lead our industrial society. We have had ample reasons to believe that the quality of *Rikei* education would be well sustained throughout the modern history of Japan as we were successful both in the modernization of the county from the end of the nineteenth century and in the quick industrial recovery after the complete defeat in

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*,
International and Development Education,
https://doi.org/10.1007/978-3-319-98666-1_10

World War II. The recent increase in the number of Nobel-prize winners in various fields of science—now ranked third after the US and UK since 2000—also supports this view.

However, we are not so optimistic anymore. Many experts, for example, Professor Yoshinori Osumi, a Nobel-prize winner in 2016, are warning that science in Japanese higher learning is now in crisis. Laboratories, especially those of pure sciences, are suffering from the lack of research funds. In addition, the young generation's interest in the *Rikei* field is obviously declining. The slump is caused by the developmental processes themselves, and most of the problems are deep-rooted. Traditions and customs in the Japanese system, once considered advantages, make it difficult to define the problem. Michael Burrage, of the London School of Economics, once said that "universities have a life beyond formal pedagogic or management models" and, to understand them, he suggested identifying "their peculiarities as communities" (Burrage 1998). This suggestion was made in the context of explaining higher education in England, but I think that the method may be useful in analyzing our problems in STEM learning. In this essay, I confine myself to raising questions in the *Rikei* fields, but some of the problems pointed out are commonly observed in other fields of higher education in Japan.

Historical Perspective 1: Professional School Origin[1]

One aspect of Japanese universities is the predominance of practical fields over genuine academic ones. This may have derived from practical attitude of the nation. In the middle of the nineteenth century, when they were exposed to western civilization after isolation for nearly 250 years, what impressed them the most was neither freedom nor human rights but the steamships of the US Navy that appeared in Edo Bay. Commodore Matthew Perry came with his fleet and guns to negotiate with the Tokugawa government about the opening of Japan to the United States. At their first sight of these battleships, the Japanese

[1]The modern Japanese education system started from 1872 (Meiji 5). Originally, the establishment of the university was aimed, but, for various reasons, some of the "imported" professional schools preceded, instead. "Professional School" here refers to those pioneering schools. The present professional schools (Senshu-gakko or Senmon-gakko) basing on the *School Education Law* modified in 1975 belong to a different school category and have no relevance to the professional schools in the old system.

perceived the power gap between Japan and the United States, and the leaders determined immediately to construct the same kind of ships by themselves. Only three years later, a boat with a steam engine succeeded in crossing a small bay off Shikoku island, though in a somewhat hesitant manner. It was built by a traditional lantern craftsman, Kozan Maebara, who was assigned and hired by a landlord, Muneshiro Date, for his excellent skills in handicraft. As exemplified by this episode, Japanese people have paid much more attention to the products of the west than to its civilization.

Soon after the Meiji Restoration in 1868, Japan aimed at catching up with the west in the educational system of *Kogaku* and accomplished remarkable progress in this particular field. The word *Kogaku* used to be equivalent to engineering such as mechanical engineering and civil engineering, but now, in addition to the original meaning, it refers to a wide range of technologies, including materials science, pure and applied chemistry, applied physics, information science, etc. The new government established the *Kogaku* Institute in Tokyo in 1871, which was reorganized as the Imperial College of Engineering two years later. In 1877, an American professor of engineering, William Wheeler, visited the institute equipped with modern machine shop, woodworking shop, etc. He was sent by the American government together with William Clark to help found the Sapporo Agricultural College in Sapporo (virtually, the Agricultural and Engineering College). He wrote to his mother that "… it is equal in design, as it undoubtedly will be in accomplishment, to any in the United States…, superior in fact, in a practical point of view" (Maki 1996).

The Imperial College of Engineering became a prototype *Kogakubu*—meaning Faculty of Engineering—in the Imperial University established in 1886. *Kogakubu* grew quickly to a grandiose organization in the Japanese system. The other Imperial Universities, established successively until the outbreak of World War II, exactly emulated the system. Nowadays, in 2008, the number of students accounts for 139,000 in the national universities, about 30% of the total undergraduate students. This is an enormous number.[2]

[2] See *the Summary of Discussion: "Toward Establishment of Undergraduate Education"* reported in 2008 by University Section, Central Council for Education in the Ministry of Education, Culture, Sports, Science, and Technology—Japan. The statistics of the present Japanese higher education systems are collected in the appendices.

It is well known that the culture of *Kogakubu* was similar to that of the University of Glasgow, from which the learning system and human resources were imported. The higher education system in Scotland was the most advanced then among those of the United Kingdom, under the direct influence of continental Europe. It was the University of Glasgow that accepted engineering professors as regular members of the university faculty for the first time in 1840 (Ashby 1958). Such a state-of-the-art discipline was welcomed in our technology-oriented people and the planning was considered as promising from the beginning. The remarkable growth of the *Kogakubu* system in Japan attracted much attention and investment in its distinctive organization with the following characteristics.

1. *Kogakubu* accepted only highly qualified and prepared students for specialized subjects. In high schools, the preparatory schools for imperial universities in the old system, the program consisted of liberal arts and sciences, but emphasis was put on mastering foreign languages such as German, English, and French, depending on the future major. For candidates for *Kogakubu*, English was highly recommended.
2. The organization was tuned to the governmental planning for the development of industry. Brand new departments were quickly introduced to the faculties in synchronization with, sometimes ahead of, emerging new industries.
3. The programs were so organized that the graduates could cope with the emerging industries. Emphasis was put on laboratory work and practical training. Many of the *Kogakubu* graduates played principal roles in creating and promoting new industries in Japan.

The originality of *Kogakubu* is attributed to Henry Dyer, who was invited from the University of Glasgow to initiate the college but, besides his personal effect, the interaction between him and his Japanese students should not be overlooked. Most of his students were from the samurai (*bushi*) class. Soon after the Meiji Restoration, the class system was abolished, but the families belonged to the *bushi* class were registered as *shizoku* (samurai tribe) and their lives were supported by a new government bond issue. The number of the students from *shizoku* families was up to 72% in 1885, 12 years after the foundation of the college

(Amano 1983). Considering the fact that the number of the *bushi* families, including their relatives, never exceeded 7% of the total population during the feudal times and there was no discrimination with regard to enrollment, this number was extraordinary. The college was, in this sense, a school for the descendants of samurai. The educational spirit of Scotland in the nineteenth century was thus combined with the *bushi* morality (*Bushido*) to form the habits of mind of *Kogakubu*.

It was accepted, at least until recently, that the *Kogakubu* graduates were well disciplined, skillful in solving problems in team play, and took it for granted that they were royalty and dedicated to their organizations. Besides, most of them had a broad perspective and respected the common tenets of the society. Owing to this, the *Kogakubu* graduates were welcome in Japanese society, and the manufacturing industries themselves came to share the same virtues. As a result, Japanese industries as a whole became strong, efficient, and cooperative with universities in the modernization process. The *Kogakubu* education became the mainstream in the Japanese higher education system as far as the public sector was concerned.

Historical Perspective 2: The German University Origin

Another aspect of the Japanese system is typically reflected in the faculties of science. When the University of Tokyo, a prototype of the first university in Japan, was founded in 1877, a school for science and one for letters were included. The two schools were supposed to cover liberal arts and sciences in "western studies." They were promoted to the faculties of Science and Letters, respectively, when the Imperial University, the first German model of higher education, was established. It should be noted that the German research ideal was implanted in Japan separate from professional schools such as the Imperial College of Engineering and Sapporo Agricultural College.

When Japanese joined the world of science, the German universities were at their peak and Europe was attracting many talented young scientists from around the world. Although Japanese were latecomers, it was not too late to participate in the construction of modern science. For example, in the field of physics, quantum mechanics, a revolutionary theory dealing with the behavior of matter and light on the atomic and subatomic scales, was established in the early twentieth century. Although no significant contribution by Japanese scientists is known to this theory, some Japanese were given opportunities to work with the prominent scholars such as Niels Bohr and Ludwig Boltzmann. They observed important scenes where epoch-making breakthroughs were made. They returned to Japan and conveyed the exciting atmosphere of the laboratories to another generation and provided fertile soil for the fostering of young scientists. Significant contributions by Japanese scientists, particularly in the fields of theoretical and experimental physics after World War II, were made after a long approach run overcoming the difficulties brought about by successive wars.

In the Japanese universities, the German model was well retained at least until World War II, though it was never the mainstream in higher education because of the lack of a formal PhD machine. The German model in Japan, a little different from the original one, is characterized as follows.

1. Pure science was aimed at industrial application from the early time. A typical example is the Faculty of Science in Tohoku Imperial University established in 1911 as the third German-type institute in the field of science. To differentiate it from the preceding institutes, the founding fathers focused on utilizing the results of pure science to create new materials. Such an attitude is now widely seen all over the world, but it should be noted that the practical application of science was considered a sort of deviation from the academic norm then.
2. Their bilingual nature, but not in its genuine meaning, in research and training. The Ministry of Education planned to use the mother tongue as the official language in the educational system as a whole, but the very top universities and professional schools were outside the rule. So then German, and later English, was used for reading and writing, and Japanese was for discussion and personal communication.
3. The students were obliged to do intensive research work in the last stage of the undergraduate program. Traditionally, the students in the *Rikei* fields were supposed to spend one or more years in a professor's laboratory like the students in German universities. However, it was for the Bachelor's degree in the Japanese system, not for the Doctorate degree. Later, the difference entailed "compressed" undergraduate programs and a relatively weak PhD machinery in the Japanese universities.

Language for STEM

The question of what language should be officially adopted in the higher education system was one of the headaches for the Ministry of Education. The issue was debated not only for higher education but also for other modernization schemes of the country. After try-and-error processes, the following conclusion was drawn in the early Meiji era. In the top-class schools such as Imperial Universities and some of the prominent professional schools, textbooks written in the original languages, meaning German for science and medicine, English for engineering and agriculture, and French for law, were adopted. In ordinary professional schools and secondary or lower schools, textbooks written in Japanese were used exclusively.

To do so, all of the technical terms and expressions had to be translated into Japanese for all the academic disciplines. This was possible because the so-called "*Yogaku*," western studies, mainly based on information from Holland and Germany, had been conducted in Japan since the late-eighteenth century, despite a formal prohibition during the Edo era. Besides, many translations had been carried out in the early Meiji era and glossaries for major professional and academic fields were available since the late 1890s (Amano 1988). Many of them were used simultaneously by Chinese and Koreans. This educational strategy, limited use of foreign languages in the limited institutes, of the Ministry of Education was obviously under the influence of elitism and seemingly against egalitarianism. But, from a different point of view, except for a handful elite students in Imperial Universities, whose number never exceeded 2% of each generation in the old system, education was opened to ordinary people in terms of language. This is important for analyzing the STEM issue in Japan, because it provided fertile soil for grass-roots STEM learning, leading to the quick industrialization of the country.

Meanwhile, the language problem moved to the next stage. In the professional schools like the Imperial College of Engineering, the official language became Japanese in the mid-Meiji era. Foreign professors were replaced by home-grown Japanese, who began to write textbooks in Japanese. Thus, from the top to the bottom, meaning from the Imperial University to the domestic elementary schools, the STEM learning was conducted mainly in Japanese without the help of foreign languages. Thus, using the Japanese language, universities and colleges were long able to make do and create unique features within them: World War II and the following occupation period enhanced the isolation from the outer world. Except for a handful of science majors, the majority of the undergraduate students have given no priority to English or other foreign languages until recently. It is now a growing issue again in the Japanese universities under the predominance of globalism.

Status Quo and Comparison to the American System

The two different currents in Japanese higher education, one from the professional schools and the other from the German universities, suddenly came to an end after World War II because the American occupation army under the command of Douglas MacArthur (GHQ) did not allow the continuation of the old system. From an American point of view, the system seemed to be hierarchic and was considered to be a hotbed of "militarism." According to recent studies, however, it turned out that the Japanese side also had seriously considered a complete reform of the system before and during the war and helped MacArthur reform the system immediately after the war. There is no space to discuss the details of the changes here but, briefly, different kinds of higher education institutions, including liberal arts colleges, vocational schools, colleges of education and high schools were all reorganized into the four-year universities of "the new system." The former Imperial Universities also joined in the new system. At the same time, as a result of a strong suggestion by the GHQ, a collegiate element in the American style was implanted in the form of a general education program. It was confined, however, to the first half of the undergraduate programs and most of the Japanese universities were not able to overcome its improvised nature.

In actuality, each of the two elements described above in the Japanese system was kept intact until the 1960s with its elitist nature. A structural change occurred in the 1970s and 1980s due to the continuous increase in the number of students and, in addition, due to the student movement in major universities. Concerning STEM education, the growth of both *Kogakubu* and faculties of science was remarkable. Among them, the expansion of *Kogakubu* caused a fundamental change in its nature and the effect spread to other professional-type institutions in general. Originally, each department in *Kogakubu* was designed to fit a corresponding industry, but the composition of industry in Japan began to change quickly and *Kogakubu* had to create new departments in a hurry. This was done without fundamental reorganization of the old system, resulting in grandiose, complicated, and divided organizations. Besides, the German research ideals prevailed over the habits of mind of professional schools. At present, the two elements in the old Japanese system are blurred and most of the faculties and departments are classified as something in between.

Whether *Kogakubu* and other disciplines in the *Rikei* field could be qualified as "professional" or "vocational" is arguable. In a strict sense like the one for medical school, at least, a majority of the *Rikei* disciplines, including *Kogaku*, agriculture, fishery, and even pharmacy, should not be classified as professional ones. For example, only a few of the graduates from electrical engineering departments become real electrical engineers. Rather, the majority of graduates engage in various jobs, and even in the banking business nowadays. Before, the graduates were so qualified that they were promoted to the administrative side after working for a while in laboratories, factories, construction sites, etc. At present, the working environment changes so quickly that it has become the norm to be shifted from one job to another within a short time. For these reasons, in the *Rikei* field, what is vocationally relevant is not axiomatic anymore and, as far as the undergraduates are concerned, it is not asked about in detail by the stakeholders. The word *Jitsugaku* (meaning "practical studies") is preferred instead of "professional study" in Japanese higher education. In my view, most of the *Rikei* disciplines can be classified as *Jitsugaku* studies nowadays.

Figure 10.1 shows the structure of the Japanese system, including graduate and undergraduate institutions. In addition to professional and academic disciplines, the *Jitsugaku* disciplines occupy a large part of the system. The professional part is composed of medical schools, schools of health sciences, law schools and, in part *Kogakubu*. A typical academic discipline is natural science, but many of the departments in *Kogakubu* are also classified as this. In other words, *Kogakubu* has a very wide spectrum comprised of professional disciplines and academic disciplines. The former disciplines have relevance to classical engineering and the latter to technology-related sciences, with the latter prevailing. Many say that this shape of *Kogakubu* is not bad, but rather shows a new trend in the universities. This may be true but, before judging so, several problems have to be solved.

In the *Jitsugaku* field, each department has been established to respond to the society's demand. As the society changes quickly, the departments become diversified. According to a survey of the Japanese

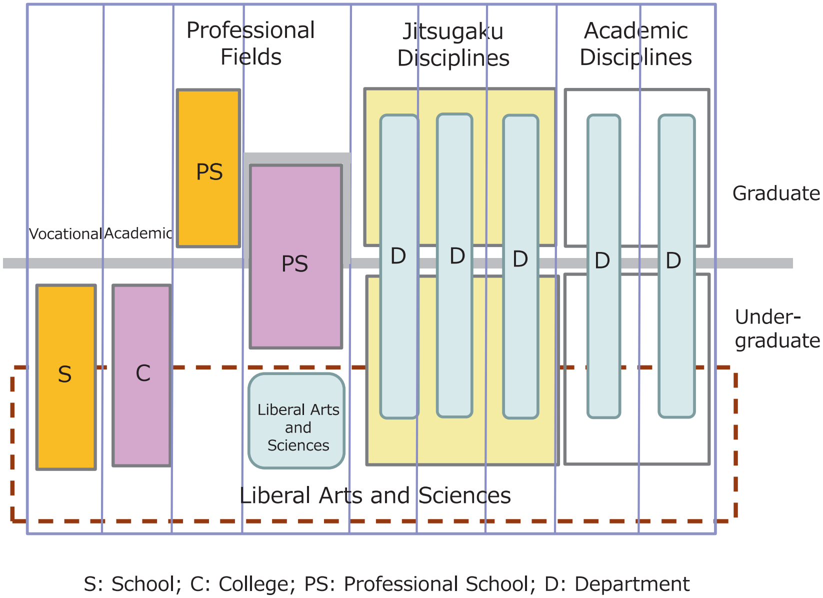

Fig. 10.1 Structure of the Japanese higher education system

Ministry of Education, Culture, Sports, Science and Technology, the number of names of Bachelor's degrees in the Japanese system was as large as 580 in 2005.[2] Such a way of naming disciplines is not common in the rest of the world and the deviation from the standard makes program quality assurance difficult.

In most of the Japanese system, each department has a vertical nature in terms of the curriculum and students' choices. The organization is self-contained with no interaction with others. The students entered into a department are expected to stay in the same place until finishing the graduate programs, usually those for a master's degree. The restriction causes two serious problems. For students, changing majors is not easy, or actually impossible, and the students' choices, including research work, are also limited to a narrow range. For the teaching staff, as the quality of students is diverse, much more time is needed to maintain the quality of the class. It is not possible, or at least difficult, to assign the courses run by other departments to their own students even if the courses are useful for them. As a result of the alteration of the *University*

Establishment Law in 1991, the liberal education approach was eliminated in many universities. In addition, owing to the lack of a systematic approach to teaching of natural sciences and mathematics, maintaining the STEM level required for the undergraduate program is becoming more and more difficult.

Confronting these difficulties, specialists in higher education recommend that we refer to the American experience with undergraduate programs. It is known that, in the United States, graduate training and research retain much of the structure and culture of the traditional American college around which the new universities grew. Robert E. Kohler wrote that "Research was valued because it was thought to make college teachers better at their jobs. Research was justified in the language of collegiate values because it was part of a collegiate reform movement. The training of researchers was carried out in close connection with advanced electives" (Kohler 1996). This is an enviable tradition for Japanese professors who are working in STEM education under the specialized tradition of the universities. In contrast to the American universities, our system lacks a collegiate background despite repeated efforts to introduce liberal education into the undergraduate programs.

There is no doubt that the universities acquired a leading role in scientific research and in training professional researchers. But, what is our cultural base on which the German research ideals work? The habits of mind for the professional schools are fading away as explained before. I myself find, behind the fading images of the imported professional school spirit and the collegiate mind, the tradition of *Juku* culture. The *Juku* originally was a kind of private school that first flourished at around the time of the Meiji Restoration and is again flourishing "now." The *Juku* was an organization with a teacher and privately recruited students around him/her, typically with a class size of less than 50, where intimate communication was possible. For me, the *Juku* seems to be similar to the classical English universities described by Michael Burrage (1998).

> Informal, integrative institutions, which were often taken for granted, often considered peripheral, which often had nothing whatever to do with organized curriculum, and with formal pedagogic relationships, mitigated the fragmenting effects of disciplinary or departmental specialization.

Western studies in the late Edo and early Meiji eras were carried out mainly in *Juku* such as the *Keio-gijuku* in Edo and Tokyo. In Osaka, without the *Teki-juku*, the introduction of western medical science into the then feudal society would not have been possible. At present, *Juku* (cram schools) helping students prepare for entrance examinations for universities are a big business, though their structure and function are quite different from the original type.

It is the experimental sciences that mainly benefited from this culture of training students. Each laboratory has a cohort system with PhD students being at the top and undergraduate students at the bottom. This system trains newcomers how to behave in the laboratory, how to make a presentation, and how to write a paper. It is a place for installing the virtues of work and discipline, the habit of team play and even for moral improvement. Without this system, the Japanese universities, especially research-oriented ones, would never be able to accomplish their purposes. The German research ideal found a comfortable place in this tradition of learning and accommodated to the present competitive environment. The laboratory is the very core of the Japanese system.

On the other hand, the laboratory system has a potential danger for STEM education because it relies on the free labor of undergraduates and graduate students. In the American collegiate system, the career aims of these laborers shape the way problems are selected and worked on. But, in the Japanese system, the choices of the students are confined to the narrow range of the department that the student chose upon enrollment in the university. Another danger is that the quality of the laboratory depends very much on the personal ability or character of the professor. There is a good chance for students to fail in laboratory work because there is no regulation or formal curriculum in the laboratories. A laboratory run by a narrow-minded professor easily becomes exclusive of others and forms a kind of closed system with little freedom for students. Finally, the problem of overemphasizing the laboratory training, which results in a tendency for both the students and professor to take coursework too lightly, should be noted. This reflects on the method of counting the required credits for the Bachelor's degree as explained in the next section.

What Should Be Done?

What is to be learned from the Japanese experience in the *Rikei* field? Modern science and technology were successfully implanted in the soil of craftsman and *Bushido*. At the core were interactions between ambitious, authentic, and hard-working professors with elite students who had aspirations. The cultural background and adventurous spirit of the nation at that time also played important roles. But, in contrast to the successful start and development, we cannot expect any bright future for the next generation now. The problems to be solved are serious and deep-rooted: (1) the decline of interest in the *Rikei* field, (2) language problems, (3) too much specialization, (4) weak machinery for STEM learning, and (5) a weak PhD machine. My point is simply that an elite system of university education is a thing of the past, and it is the time to adapt the mass stage of higher education and to prepare for a knowledge-based society. Some *Rikei* departments and programs have developed reforms in order to deal with mass university education. But, so-called elite universities, in terms of higher enrolment qualification, favor over the traditional way of training, that in turn helps to sustain the out-of-date norms in either coursework or research work in non-elite universities. I have no intention to deny the basic conditions that helped us succeed in the past. These include a sense of community, teacher-to-student and student-to-student interactions, and the cultural background. But, there is room for improvement in many respects, as exemplified by the following points.

I recommend each department of the *Rikei* field to open the courses and to give more freedom to the students. The structural reforms made in the *Rikei* field in the past responded to social changes and an increase in the student number was inevitable. But the present departments are too narrow and too specialized. Considering the fact that the graduates go to various workplaces, the curriculum has to have a wider perspective. Besides the departmental courses, emphasis should be put on the liberal arts and more systematic STEM learning.

I also suggest that research work has to be positioned appropriately within the coursework. Research work is at the very core of even the undergraduate program in Japanese universities, but it is not in a proper position in the curriculum. The number of credits for research work is usually not more than 10, less than 10% of the required credits for the bachelor's degree. Actually, in the *Rikei* field, the timetable for seniors is open, allegedly so that students can devote themselves to research work. As a senior is supposed to spend the whole day in the laboratory, the actual credits for the research work could amount to as high as one-fourth of the total time necessary for the bachelor's degree. This discrepancy makes the actual time available for coursework short. Altogether, it is only three-quarters of the total time. This is the reason why the credit system has not been substantiated yet, despite the repeated warnings of the University Council and the Central Council for Education since 1998 (University Council 1998). It also gives rise to the peculiar custom of juniors and seniors spending too much time, usually one whole year, job hunting. Nowadays, most of them are not satisfied with acceptance from one company but tend to collect more and more acceptances, sometimes up to 10.

Finally, and by way of conclusion, I would like to insist that STEM has to be integrated in some way we chose. Science nowadays is difficult for students to appreciate it as a whole. Especially in Japan, the STEM subjects have for long been utilized for selecting students for higher level universities and, as a result, students tend to confine their interest from a young age to limited fields of science in order to get better marks on exams. Their knowledge as well as their interest in science is so divided and fragmented that a wider perspective is beyond their scope. This is the reason why they lose their interest in the *Rikei* field soon after entering the universities. On the other hand, owing to the recent remarkable progress in science and technology, our view is extending considerably both in the direction of the microscopic world and to the cosmos. We are now living in an exciting era of science and technology. In the university curriculum, the introductory part, at least, of the sciences and technologies should be integrated. The integrated science and technology should be presented not only to university students but also to ordinary people. Spanning the departments and faculties, we have to construct a learning network that links a variety of subjects. If such a network is accessible, it will benefit ordinary people as well as university students. It is also important to make the walls around the disciplines as low as possible and give students the freedom to move to other disciplines. The world of science and technology is intrinsically one world in which everybody, regardless of age, sex, race, and nationality, can communicate with each other and enjoy its fruits.

References

Amano, Ikuo. 1983. "*Shiken no Shakaishi: Kindainihon no Shiken, Kyoiku, Shakai*," in Japanese, 260. Tokyo: University of Tokyo Press.

Amano, Ikuo. 1988. "*Daigaku - Shiren no Jidai*," in Japanese, 63. Tokyo: University of Tokyo Press.

Ashby, Eric. 1958. "*Technology and the Academics: An Essay on Universities and the Scientific Revolution*," 56. London: Macmillan.

Burrage, Michael. 1998. "The Curious Case of General Education in England." *Journal of Higher Education and Lifelong Learning* 3: 14–18. Center for Research & Development in Higher Education, Hokkaido University, Sapporo.

Kohler, Robert E. 1996. "The Ph.D. Machine, Building on the Collegiate Base." In *The Scientific Enterprise in America, Reading from ISIS*, edited by Ronald L. Numbers and Charles E. Rosenberg, 98–122. Chicago and London: The University of Chicago Press.

Maki, John M. 1996. "*William Smith Clark, A Yankee in Hokkaido*," 141. Sapporo Japan: Hokkaido University Press.

University Council. 1998. "*A Prospective Image of the Universities in the 21-st Century and the Reform Strategy*," in Japanese, 46–48.

CHAPTER 11

Concluding Remarks

Aki Yamada

Advances in science, technology, engineering, and mathematics (STEM) research and development are core to economic growth and the creation and growth of new industries, which manifest themselves in the products and technologies that we use in our daily lives. STEM fields are widely acknowledged as essential for global economic competitiveness in the twenty-first century. From an economic standpoint, a 2012 US Congress Joint Economic Committee cites that approximately half the US economic growth in the last 50 years was driven by productivity gains due to technological innovation (US Congress Joint Economic Committee 2012). Globally, higher education reform is sought to proactively handle new trends in globalization, internationalization, and the rising demand for STEM field graduates. This reform in response to globalization and STEM demand is often intertwined, as globalization of higher education has affected who are studying STEM and their education and workplace opportunities. The transformation from elite higher education systems to massification and a globalized knowledge economy has opened

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*,
International and Development Education,
https://doi.org/10.1007/978-3-319-98666-1_11

doors internationally for many new students. A 2015 United Nations Educational, Scientific and Cultural Organization (UNESCO) report estimates that graduates from China and India combined will account for 60% of the G20 workforce with STEM qualifications by 2030. With many countries projected STEM graduate needs outpacing their current domestic graduation rates, there is fierce competition for this emergent global talent pool (United Nations Educational, Scientific and Cultural Organization 2015).

Combining the challenges posed by globalization and the demand for high-quality STEM graduates, higher education reform needs to prepare STEM students to innovate and solve important problems that stretch beyond geographic, cultural, sociopolitical, and domain-knowledge boundaries. Trends toward greater globalization and internationalization necessitate the development of leaders who have the skills and knowledge to operate, compete, and succeed at the global level. Thus, in addition to typical expectations for the development of STEM students with advanced knowledge and technical capabilities, higher education reform seeks to enhance the quality of its graduates by further developing interdisciplinary knowledge and soft skills needed to adapt to ever-changing modern workplace needs.

Asia Pacific countries are looking to adopt new curriculums that enhance global competencies through internationalization and the integration of social sciences within the STEM fields. This volume draws cases from across the Asia Pacific region to look at the critical STEM issues and the challenges of bridging the fundamentally different points of view between different fields and disciplines. Despite many fields of science having been borne from philosophical roots, we are now at a point where the sciences and humanities have become largely categorically separated at the institutional level. Despite the differences between STEM and social science and humanities (SS/HUM), there are considerable opportunities for these fields to collaborate and enhance each other through a STEAM education model, which incorporates the arts into STEM for a more holistic approach to technical knowledge.

> STEAM is a call to arms, for an overhaul of how we train teachers and administrators, how we inform our politicians, and the biggest challenge of all, how we significantly increase parental involvement. In many ways, realigning the arts with the sciences puts trust back in the teachers and their capabilities and instincts and makes for a more exciting, creative and successful environment. (Sousa and Pilecki 2013, p. 242)

It is important to look at liberal arts in a pedagogical manner, examining both what is being taught and the methods used to effectively teach. Western pedagogy and active learning techniques that develop soft skills are being utilized to prepare graduates to undertake collaborative work with experts across different academic fields, and to work in teams where team members supplement each other's skills and knowledge. At the individual level, technical research skills are increasingly being combined with broader knowledge from international and interdisciplinary studies. Many chapters in this volume have examined the differentiation of STEM and SS/HUM from historical and modern perspectives. A modern shift in this paradigm identifies the value of these two fields complementing each other for meaningful benefits at their intersection. This volume has shown the importance for STEM and SS/HUM fields to work together in order to be engaged in critical thinking, evaluate problems from multiple perspectives, formulating and discussing solutions to real-world problems that span disciplines and geographic borders. Interdisciplinary studies help develop expressive language skills and result in deeper scientific, social, and humanitarian understanding. Thus, encouraging further collaboration between STEM and non-STEM fields, such as SS/HUM, are indispensable.

Throughout the Asia Pacific region, countries are undergoing higher education reform seeking to develop global human resources as capable world-wide leaders. In Asian countries where English is not the official language, such as Taiwan, South Korea, China, and Japan, higher education institutions are actively recruiting foreign students, faculty, and researchers to help develop English speaking internationalization, global research networks, and international competitiveness. Aspects of STEM-driven reform manifest differently in each country, for example in Japan, universities are developing strategies to significantly boost foreign enrollments to supplement a diminishing population and workforce. Yet Japanese society illustrates the difficulty of true internationalization, as Yonezawa (2014) points out, many youths still maintain "inward looking attitudes" (p. 46) and skepticism toward the need and marketability of global skills. Most students believe they will seek domestic employment, and in entry-level positions they are unlikely to realize gains from foreign language ability or cross-cultural training in their daily work.

In the current context of intense competition for STEM graduates and higher education world rankings, institutions face critical decisions in allocation of funds, and modifications and improvements to existing teaching methods. Stewart-Gambino and Rossmann (2015) frame the current divisions between STEM and SS/HUM in terms of the utilitarian and utopian. The outcomes of interdisciplinary education are more difficult to predict and measure individually in comparison to utilitarian metrics, such as jobs fulfilled, salaries, and economic output. Yet we cannot lose sight of the broader utopian values SS/HUM education can instill. Beyond the subject of pedagogy and higher education divisions, there are still pre-existing issues that warrant attention. In terms of STEM access equality, women, underprivileged minorities, and economically disadvantaged are still less likely to meet requisites for declaring a STEM major and finding success in workplace environments. New emphasis on academic and industry demand for STEM fields offers us an opportunity to work toward greater inclusion and advocacy on behalf of these groups to fulfill the growing global need. Many of the educational reform strategies outlined in this volume are relatively new and driven by long-term visions. These projects will take time to implement and we will have to closely monitor such efforts to reveal the effectiveness of reform driven by modern STEM needs.

References

Sousa, David A., and Tom Pilecki. 2013. *From STEM to STEAM: Using Brain-Compatible Strategies to Integrate the Arts*. Thousand Oaks, CA: Corwin.

Stewart-Gambino, Hannah, and Jenn S. Rossmann. 2015. "Often Asserted, Rarely Measured: The Value of Integrating Humanities, STEM, and Arts in Undergraduate Learning." *National Academies of Sciences, Engineering and Medicine*. Available online at http://sites.nationalacademies.org/cs/groups/pgasite/documents/webpage/pga_170985.pdf.

United Nations Educational, Scientific and Cultural Organization. 2015. "Education Indicators in Focus." Available online at https://www.oecd.org/education/EDIF%2031%20(2015)--ENG--Final.pdf.

US Congress Joint Economic Committee. 2012. "STEM Education: Preparing for the Jobs of the Future." Available online at https://www.jec.senate.gov/public/_cache/files/6aaa7e1f-9586-47be-82e7-326f47658320/stem-education---preparing-for-the-jobs-of-the-future-.pdf.

Yonezawa, Akiyoshi. 2014. Japan's Challenge of Fostering "Global Human Resources": Policy Debates and Practices. *Japan Labor Review* 11 (2): 37–52.

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J. N. Hawkins et al. (eds.), *New Directions of STEM Research and Learning in the World Ranking Movement*, International and Development Education, https://doi.org/10.1007/978-3-319-98666-1

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